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Trace Metals Monitoring at Two Ocean Disposal Sites

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March 1979

TRACE METALS MONITORING AT TWO OCEAN DISPOSAL SITES

by

Bruce H. Reynolds
Environmental Research Laboratory
Narragansett, RI 02882

This study was conducted in conjuction with
U.S. Environmental Protection Agency
Region III Environmental Impacts Branch
Philadelphia, PA 19106

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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FOREWORD

The Environmental Research Laboratory of the U.S. Environmental Protection Agency is located on the shore of Narragansett Bay, Rhode Island. In order to assure the protection of marine resources, the laboratory is charged with providing a scientifically sound basis for Agency decisions on the environmental safety of various uses of marine systems. To a great extent, this requires research on the tolerance of marine organisms and their life stages as well as of ecosystems to many forms of pollution stress. In addition, a knowledge of pollutant transport and fate is needed.

This report describes a portion of a four-year multidisciplinary study of two ocean disposal sites off the mid-Atlantic coast of the United States, carried out by this laboratory along with the Annapolis Field Office, Annapolis, Maryland, and the Environmental Impacts Branch, Philadelphia, Pennsylvania, both part of E.P.A.'s Region III. This portion of the investigation concerns an examination of the spacial and temporal distributions of selected trace metal concentrations in shellfish as an appropriate method for monitoring the fate and effects of two type of wastes, sewage sludge and industrial acid waste, disposed of in ocean waters.

Eric D. Schneider
Director
Environmental Research Laboratory,
Narragansett

ABSTRACT

The areal distributions of the concentration of cadmium, copper, nickel, and vanadium in sea scallop and ocean quahog tissue were examined in the vicinity of two ocean disposal sites located off the U.S. mid-Atlantic coast on four cruises conducted in 1974 and 1975. Incidental collections of the surf clam were also made on the last cruise. Patterns of metals distribution show that: (1) these metals may be used as identification tags for the individual types of wastes disposed at the two sites; (2) the distribution patterns of the metals content in shellfish may be explained to a large extent by the regional current patterns; and (3) the known toxicity of the wastes plus the demonstrated biological availability of the metals contained therein, coupled with the existence of an abundant literature documenting their toxicity in general, indicate that the wastes pose a significant threat to marine biota in the vicinity of these disposal sites.

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SECTION 1

INTRODUCTION

With the passage of the Marine Protection, Research, and Sanctuaries Act of 1972 and the subsequent promulgation of the first ocean disposal regulations by the U.S. Environmental Protection Agency in October 1973, it became apparent that considerable additional research was necessary to fully evaluate the appropriateness of the disposal of a variety of wastes in the marine environment. With the frequent occurrences of such phenomena as fish kills, oil spills, and bacterial contamination, there has been a growing awareness that the oceans are not the infinite sinks for the disposal of wastes as had been previously assumed. The effects of chronic as well as catastrophic exposure of marine organisms to various pollutants have further demonstrated the incompatibility of many of man's activities with the survival of the marine ecosystem.

With this recognition of the need for additional research, a study area of two ocean disposal sites off the mid-Atlantic coast of the United States was initiated in May 1973. The area was chosen because of its relative isolation from other anthropogenic sources of pollutants and because it included the sites used for the disposal of two typical but quite different types of waste materials. One site, the acid waste site, located 65 km. southeast of the mouth of Delaware Bay, had, since November 1968, received wastes from the manufacture of titanium dioxide pigments by the E.I. DuPont de Nemours plant at Edge Moor, Delaware. The second site, or sewage sludge site, located 9 km. southeast of the first, had been used primarily by the city of Philadelphia since May 1973 for the disposal of sewage sludge from secondary treatment. This study area is shown in Figure 1.

The objective of this research program was to evaluate the biological availability of the components of the waste materials by determining if several species of shellfish, frequently exposed to the waste, would reflect in their tissues elevated concentrations of metals contained in those wastes. It was further postulated that the distribution patterns of metals concentrations would correspond to expected directions of current transport from the disposal sites.

Species of shellfish were selected because, as relatively sessile filter-feeding organisms, they would have no means of avoiding ingestion of the components of the waste materials reaching the bottom. Metals were selected as the parameters for analysis because, in addition to being toxic pollutants in many cases, they are persistant non-degradable materials capable of being concentrated or bioaccumulated in marine organisms to

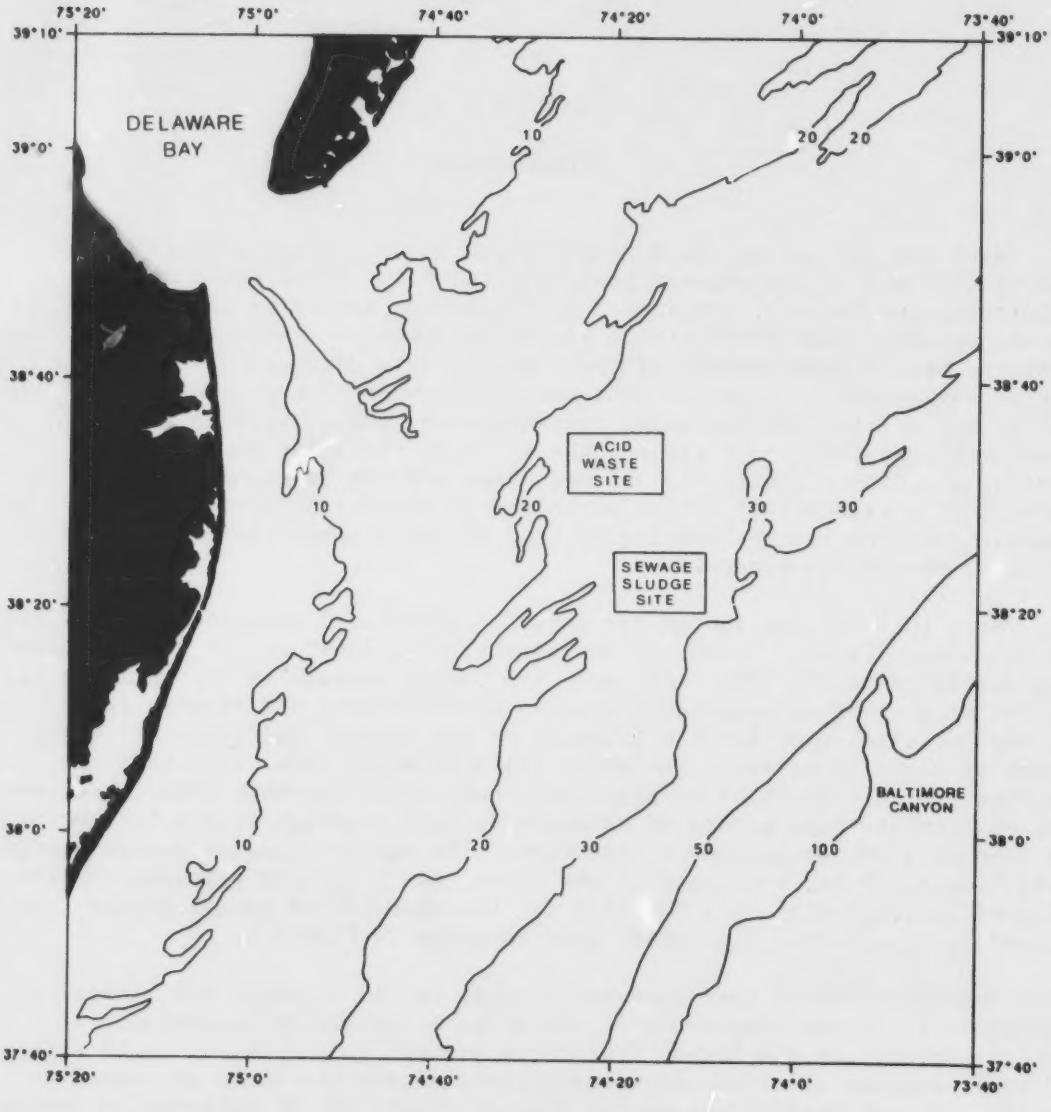

Figure 1. Study Area (depth contours in fathoms, 1 fathom=1.83 meters).

levels many times that of the surrounding waters. In this study, moreover, the metals contained in each of the two wastes were quite different. The amounts and chemical constitutents of both wastes may be estimated for the period of this study from information supplied as a requirement for an ocean disposal permit (Table 1). From an examination of the relative differences in chemical composition of the two wastes, it was apparent that metals would provide useful tags for tracing the fate of these materials. The sewage sludge, for example, accounts for most of the copper, silver, lead, nickel, and cadmium disposed in the area while the acid waste accounts for most of the titanium, vanadium, manganese, and iron.

The disposal sites, themselves, are located on a level portion of the continental shelf having sediment of medium to fine sand and water depths of 45-55 m. In general, surface currents have been observed to flow south through these sites with an onshore component during the warm half of the year and an offshore component during the cold half. Bottom currents flow south with an onshore component that persists year round (Bumpus et al., 1973). At the time of this study, both wastes were dumped in volumes of 750,000 to 1 million gallons at controlled rates into the wake of moving barges traversing the dumpsites over a period of several hours, two or three times a week.

TABLE 1. VOLUMES AND COMPOSITION OF WASTES DISPOSED AT PHILADELPHIA AND DUPONT OCEAN DUMPSITES

Total Input	DuPont*	Philadelphia∆
gal/yr	118,000,000	130,400,000
t/yr	446,700,000	493,400,000
spec. gr.	1.19	1.029
kg/yr	531,600,000	507,800,000

Individual Metal Input (kg)

	DuPont*				Philadelphia∆			
Metal	Annual (1974)	%	Total Nov 68-Dec 74	%	Annual (1974)	%	Total May 73-Dec 74	%
Fe	21,400,000	98.3	132,000,000	99.6	364,000	1.7	592,000	0.4
Cu	2,400	6.9	14,800	21.9	32,600	93.1	52,900	78.1
Cr	39,600	51.7	244,000	81.7	37,000	48.3	54,800	18.3
Al	364,000	25.0	2,240,000	55.7	1,090,000V	75.0	1,790,000V	44.3
Ag	270	10.4	1,670	31.1	2,300V	89.6	3,700V	68.9
Mn	572,000	94.4	3,530,000	98.5	33,700	5.6	54,000	1.5
Pb	5,630	7.0	34,700	2.8	74,800	93.0	1,220,000	97.2
Co	4,800	35.5	29,600	67.6	8,700V	64.5	14,100V	32.2
Ni	4,750	12.2	29,300	34.8	33,800	87.7	54,900	65.2
V	74,300	99.8	458,000	99.95	150	0.2	227	0.05
Cd	338	10.8	2,080	31.4	2,800	89.2	4,500	68.6
Zn	18,300	22.7	113,000	52.8	62,300	77.3	101,000	47.1
Ti	733,000	99.2	4,520,000	99.8	5,900	0.8	9,600	0.2

* Estimates based on DuPont reports submitted to EPA for the period Feb. 6 - July 11, 1974.

∆ Estimates based on Philadelphia reports submitted to EPA for the period Feb. 14 - Aug. 6, 1974, except where noted.

V Estimates based on EPA analysis of submitted samples of waste.

SECTION 2

MATERIALS AND METHODS

SAMPLING

Shellfish of the species Placopecten magellanicus, the sea scallop; Arctica islandica, the ocean or mahogany quahog; and Spisula solidissima, the surf clam, were variously collected on four oceanographic cruises conducted in March 1974, August 1974, February 1975, and June 1975 using half-hour tours with a 12-tooth Fall River rocking chair dredge. Figures 2-5 show the station locations for each of the four cruises. On successive cruises, some stations were reoccupied while the total area of investigations was continually expanded with new stations. Due to the patchy distribution of the organisms, not every station yielded each species for each cruise, nor were sample sizes always equal and sufficiently large for optimum statistical consideration.

Immediately upon collection, the shellfish were counted, recorded, placed into labeled plastic bags, and frozen on dry ice aboard the ship. All samples were maintained frozen until prepared for analysis.

ANALYTICAL METHODS

In the laboratory, the shellfish specimens were individually weighed, measured, shucked into clean, acid washed, and preweighed Pyrex beakers, and then reweighed. Dry weights were determined after drying at 80-90°C for 48 h. The samples were then wet digested at 85-95°C in concentrated HNO_3 until the resulting solution became clear pale yellow with no apparent nitric oxide fumes or lipids remaining. After bringing to near dryness, the samples were diluted in 5% HNO_3, filtered through No. 42 acid washed Whatman paper, and further diluted to a final volume of 50 ml with an additional volume of 5% HNO_3. Initially, all samples were analysed individually for 13 metals contained in the two wastes, using a Perkin-Elmer Model 403 atomic absorption spectrophotometer, following recommended standard operating parameters and procedures. Each sample was analysed in triplicate and the results averaged. Matrix interferences were corrected in the vanadium analysis by adding aluminum salts to the calibration standards. These corrections were routinely verified by the recovery of spikes of standard solutions added to selected samples.

The metals examined initially were silver, aluminum, cadmium, copper, chromium, cobalt, iron, manganese, nickel, lead, titanium, vanadium and zinc. These metals are those which are predominant in one or the other of

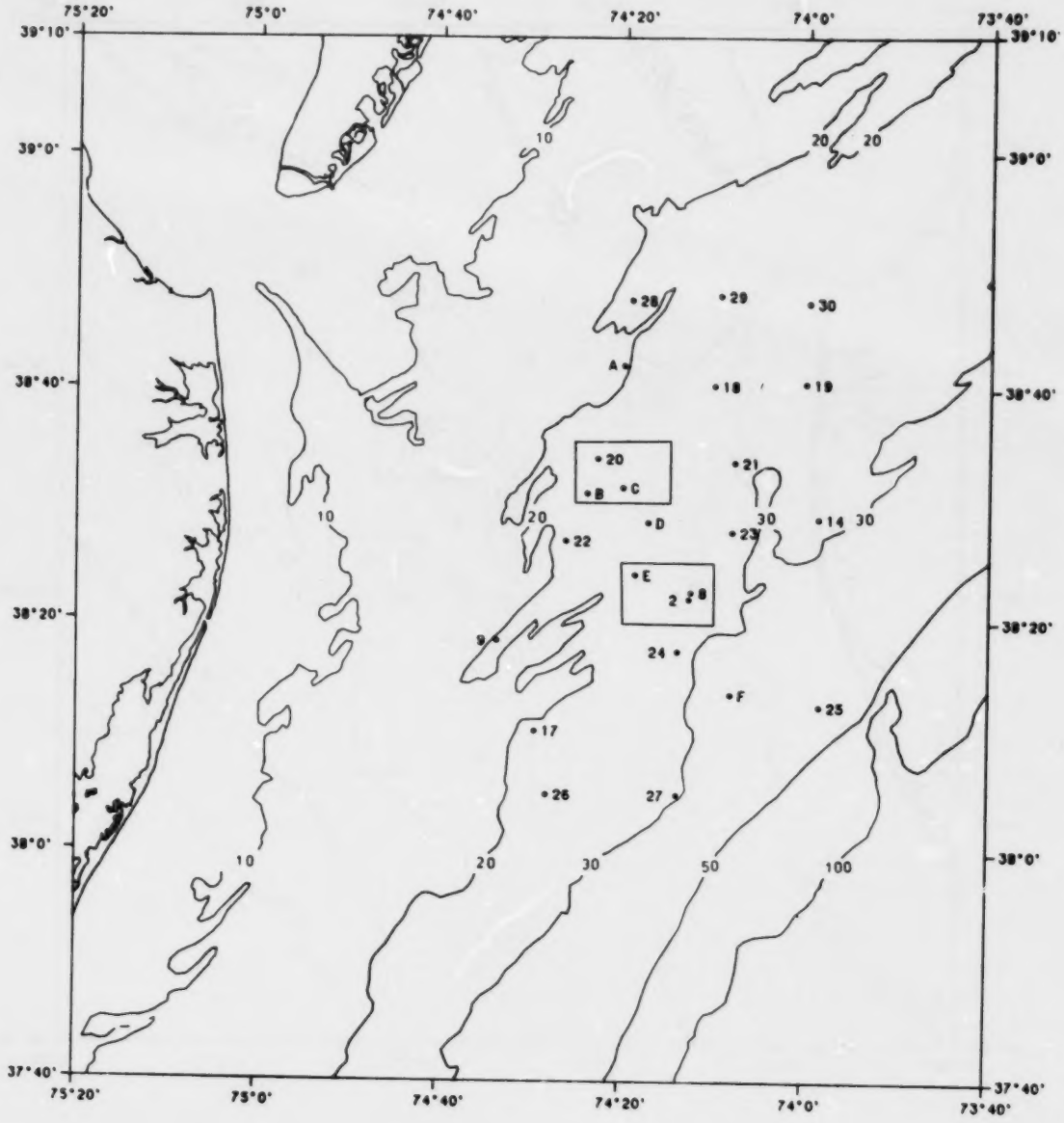

Figure 2. March 1974 Station Locations.

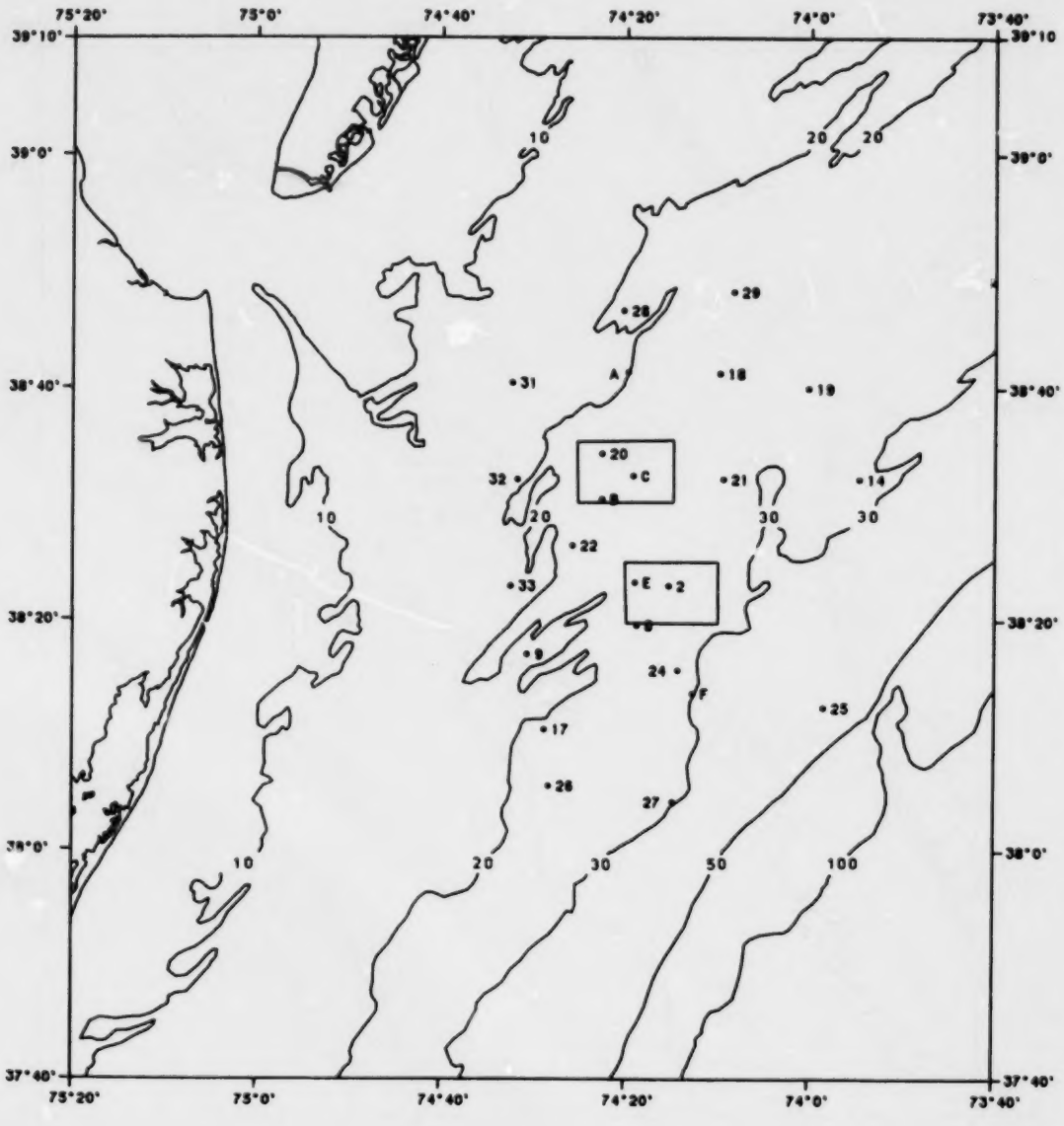

Figure 3. August 1974 Station Locations.

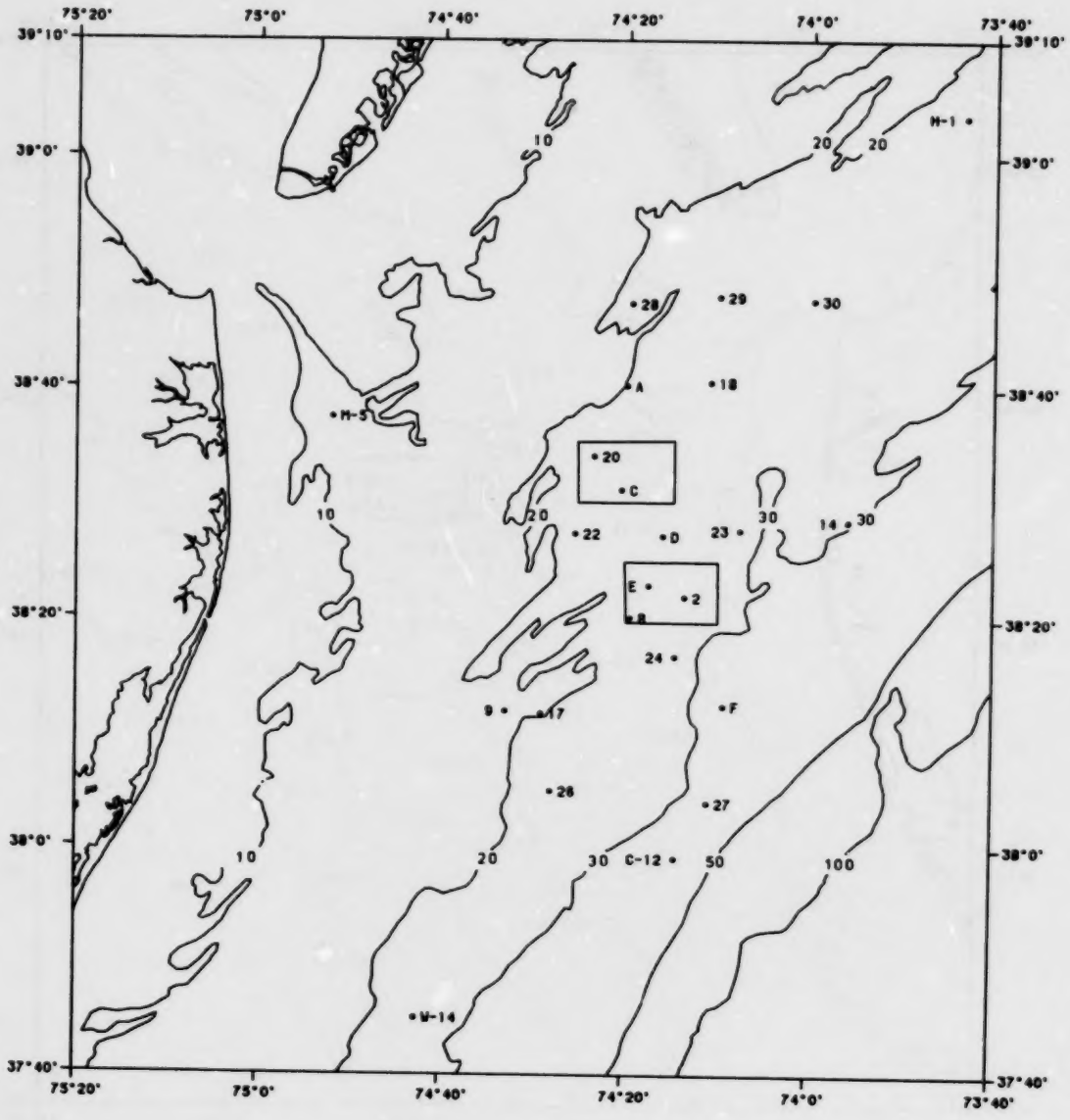

Figure 4. February 1975 Station Locations.

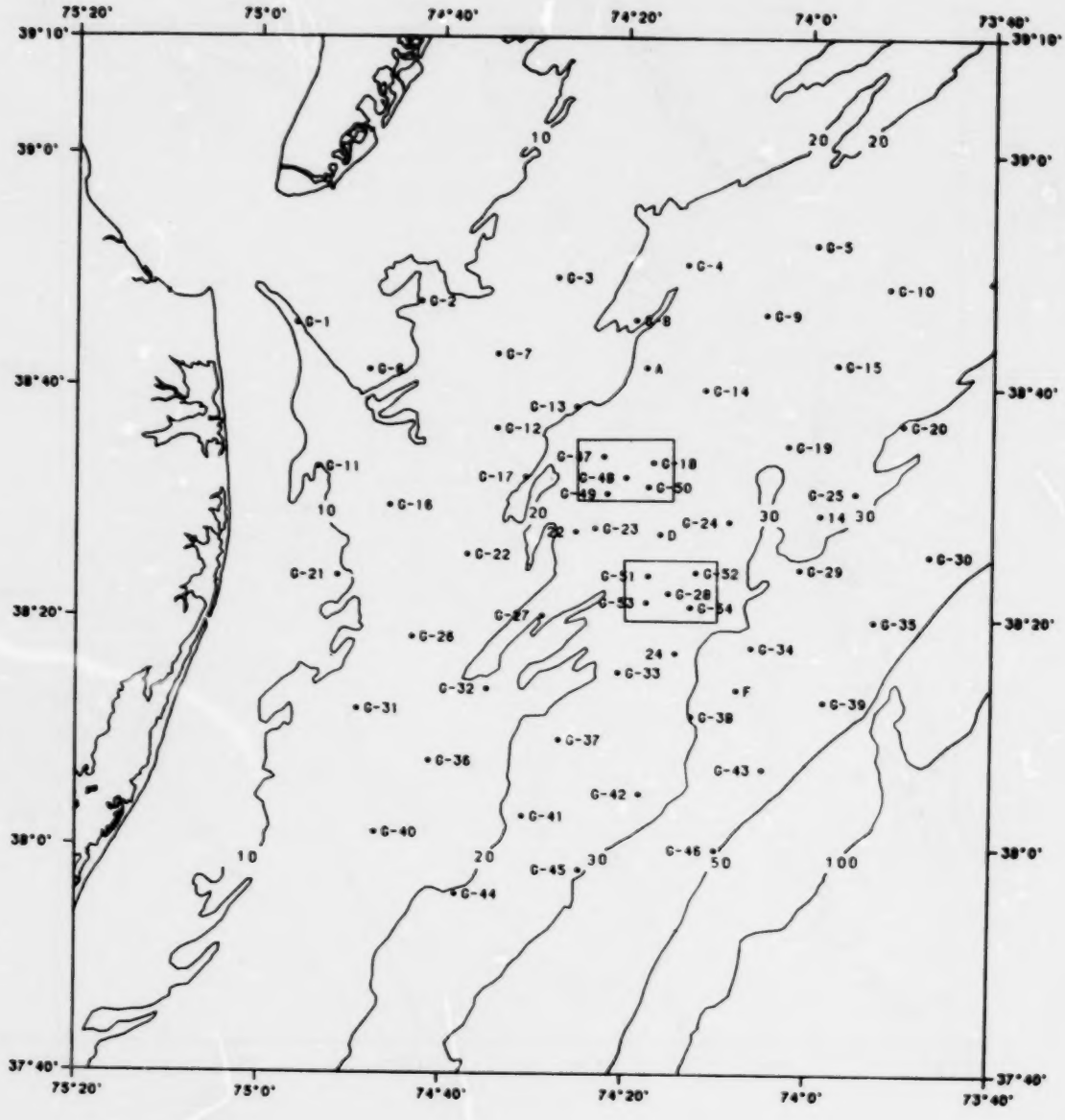

Figure 5. June 1975 Station Locations.

the two types of wastes (Table 1). After a review of the results of the first cruise, it was decided to reduce the number of metals to be examined from those 13 to 4, namely cadmium, copper, nickel, and vanadium. This was done in part to reduce the analytical demands as well as to eliminate those metals which (a) showed low levels of bioaccumulation, approaching the analytical detection limits, such as cobalt, (b) are otherwise naturally abundant and thus could possibly have been derived from included grains of sand; particularly in the case of scallop tissue, such as iron and aluminum, or (c) have subsequently been found to be subject to possible error using this analytical method, namely silver. All concentration data is reported as milligrams of metal per kilogram (ppm) dry weight of organism tissue.

STATISTICAL METHODS

The first statistical tests performed on the data consisted of a one-way analysis of variance of the 2 to 10 measurements of each metal concentrations by station, for each of the species of shellfish, and for each of the four cruises for which those species were collected. For the first cruise, March 1974, the data for the sea scallop are reported initially for the whole animal for each of the initial group of 13 metals (Pesch et al., 1977). This data, and those for the subsequent cruises, were then subjected to an analysis of variance performed separately on the metals concentration data for the adductor muscle, or edible portion of the animal, and the remaining visceral fraction. This test permitted a determination of whether significant variation existed in the data and in which fraction of the animal it occurred.

The second statistical procedure consisted of performing the Duncan's Multiple Range test on the data to define those individual stations having the significantly highest concentrations. For the first cruise, the degree of significant variation for inclusion in the Duncan's test was set at the .05 confidence level (Pesch et al., 1977). Subsequently, the threshold for inclusion in the Duncan's test was raised to the .01 confidence level for all four cruises. An initial interpretation of the results of the Duncan's test led to the selection of those stations comprising the group or subset having the highest concentrations as those being of significance (Pesch et al., 1977). This interpretation was later modified to a more conservative one in which only those individual stations in that highest subset(s) which also showed no inclusion or overlap with a lower subset were considered to be of significance. This latter interpretation, therefore, defined those stations which individually had the significantly highest metals concentrations, rather than belonging collectively to the highest group. Both of these technical modifications to procedures reported previously (Pesch, et al., 1977) were made to provide the most conservative, and thus the most defensible, approach favoring the null hypothesis (that no significant difference exists), and thus the strongest demonstration of evidence of the biological effects of the waste materials.

SECTION 3

RESULTS

Placopecten magellanicus (sea scallop)

The results of the first cruise, March 1974, are presented on Table 2, showing the mean concentrations of 13 metals for 2 to 10 individuals for each of 19 stations. The results of the analyses of variance tests (ANOVA) are also presented. The results of the Duncan's Multiple Range tests, performed for those 5 metals showing the highest levels of significance of variations (smallest P values), are presented in Figures 6-10.

It may be seen that three of the five metals identified as tags for the Philadelphia sewage sludge (silver, copper, and nickel) have their highest concentrations within the geographical confines of the Philadelphia dumpsite. Elevated concentrations are found also at stations located down current, southwest from the dumpsite (Figs. 6, 8 & 9). A fourth metal, cadmium, shows highest concentrations northeast and south of the site in a patterns having a similar orientation to the first three metals but displaced seaward of the dumpsite (Fig. 7). Vanadium, a tag for the acid waste, shows a zone of significantly high concentrations south of the DuPont disposal site (Fig. 10).

After a review of the results of the first cruise, it was decided to reduce the number of metals to be examined from 13 to 4, i.e., Cd, Cu, Ni, and V. These metals had shown the most meaningful results and consequently would reduce significantly the burden of chemical analyses. Also, since the scallops had been observed to have trapped variable quantitites of sand within their mantle cavities, it was decided to exclude specifically those metals which could possible be leached from sand during the acid digestion phase. Whereas previously reported data for samples containing sand were corrected to the extent that the weight of any sand was subtracted from the dry weight of the sample (Pesch et al., 1977), the revised suite of metals were those below detection limits in the sand and, therefore, could not present a significant source of contamination. In addition, subsequent research at this laboratory (publ. in prep.) indicates that the Ag data reported here (Table 2) and previously in (Pesch et al., 1977), are subject to possible error. The study suggests that the application of the commonly used acid digestion procedure for marine samples may not result in the complete dissolution of the Ag ion, with the result that the values thus determined may be too low. The remaining 4 metals are, nevertheless, of greatest interest since V is present almost exclusively in the acid waste while Cd, Cu, and Ni are found predominately in the sewage sludge (Table 1). The remaining 4 metals, therefore, are valid tags for the disposal operations of both DuPont and Philadelphia.

TABLE 2. MEAN METAL CONCENTRATIONS (µg/g, DRY WEIGHT) IN *Placopecten magellanicus* WHOLE ANIMAL TISSUE, MARCH 1974 CRUISE

Station	Sample Size	Ag*	Al	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Ti	V	Zn
E	10	0.58	201	11.1	0.48	3.31	6.31	400	28.8	2.64	2.80	6.03	34.3	108
F	10	0.81	904	24.9	1.02	4.56	6.81	2220	63.2	2.99	3.96	26.22	20.8	101
2	5	9.08	92	10.9	0.52	2.65	12.65	190	16.1	14.67	1.96	5.02	40.7	118
8	9	4.16	197	13.1	0.38	2.71	9.69	1040	29.4	7.84	7.09	6.76	37.2	124
9	3	0.45	92	15.6	0.29	2.64	7.54	261	24.3	2.08	2.52	4.53	39.4	116
14	8	0.48	617	59.3	0.65	2.73	6.69	1480	32.8	1.89	3.99	12.00	21.2	96
17	9	2.15	775	15.1	0.37	4.19	8.81	701	38.8	6.00	3.99	10.97	37.0	122
18	8	0.71	506	11.4	0.65	2.76	5.16	1410	41.8	1.91	2.45	17.27	21.6	96
19	3	0.39	152	37.5	0.48	2.85	4.27	565	32.2	1.06	1.84	4.98	14.0	93
20	2	1.11	313	10.8	0.78	2.01	5.63	682	22.7	1.65	1.64	16.30	19.5	101
21	4	0.64	203	14.2	0.43	2.90	5.25	1180	29.3	2.06	2.06	8.68	24.4	82
22	10	2.96	166	14.7	0.45	4.05	8.63	250	26.9	6.33	1.83	6.82	31.7	127
23	6	1.24	139	19.5	0.66	2.08	8.29	251	12.0	4.34	1.20	9.26	24.0	103
24	10	0.43	155	22.6	0.58	1.17	6.14	339	18.5	1.97	1.54	5.48	31.3	94
25	2	1.13	127	26.0	0.76	0.89	6.73	243	12.9	4.19	3.73	6.21	18.0	99
26	5	4.93	78	10.8	0.69	6.88	9.50	286	13.0	13.65	5.78	1.06	45.7	94
27	4	0.43	342	55.9	0.54	3.26	6.28	1110	22.8	1.35	6.91	9.19	16.6	89
28	3	0.46	145	10.1	0.33	1.27	4.79	576	17.1	1.09	1.22	7.35	11.4	76
30	3	0.50	229	19.6	0.38	0.94	4.01	508	30.4	1.03	1.69	8.46	13.7	107
	114													
Overall Means		1.80	338	20.9	0.56	3.06	7.31	803	29.8	4.41	3.59	9.80	28.5	105
ANOVA														
f Value		3.20	2.02	6.80	1.12	3.22	5.08	2.00	2.34	5.51	1.52	2.79	15.80	1.25
P Value		0.0002	0.0151	0.0001	0.3499	0.0002	0.0001	0.0166	0.0046	0.0001	0.0982	0.0009	0.0001	0.2389

* See Discussion on page 10.

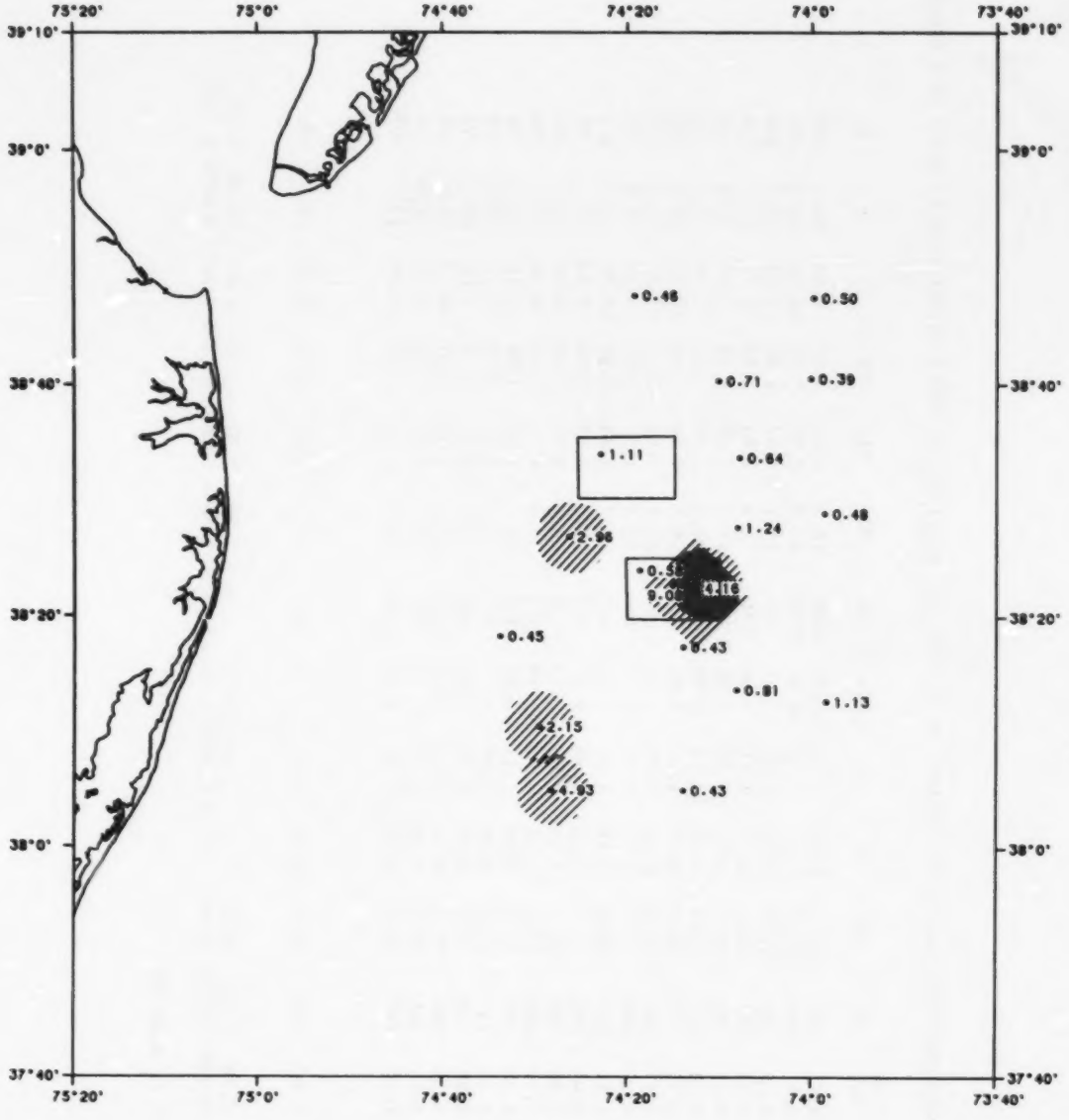

Figure 6. Mean Silver Concentrations in Whole Animal Scallop Samples for the March 1974 Cruise. In Figures 6 through 10, significantly high values are represented by a diamond; values greater than the mean are represented by a circle. See Discussion on page 10.

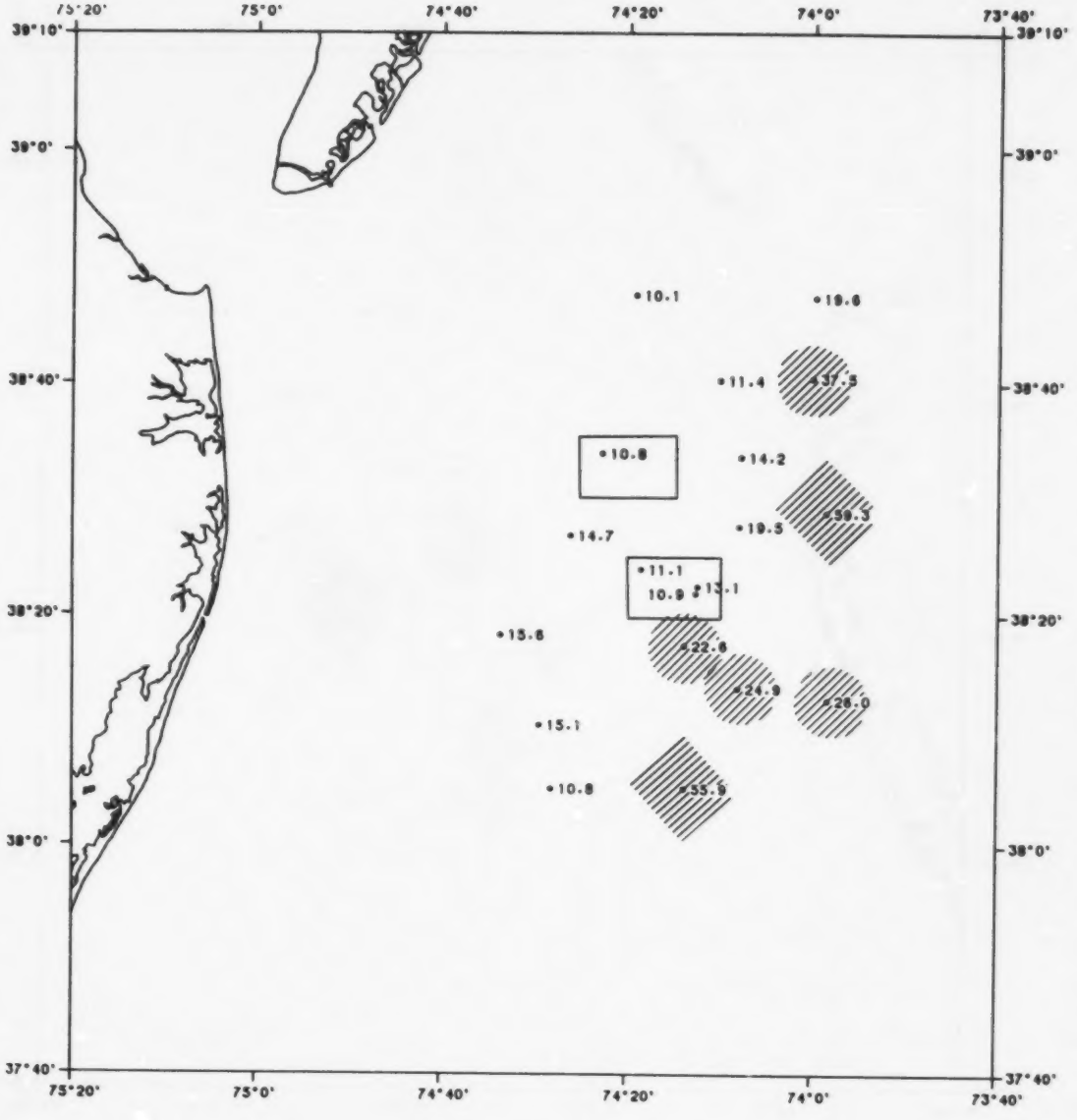

Figure 7. Mean Cadmium Concentrations in Whole Animal Scallop Samples for the March 1974 Cruise.

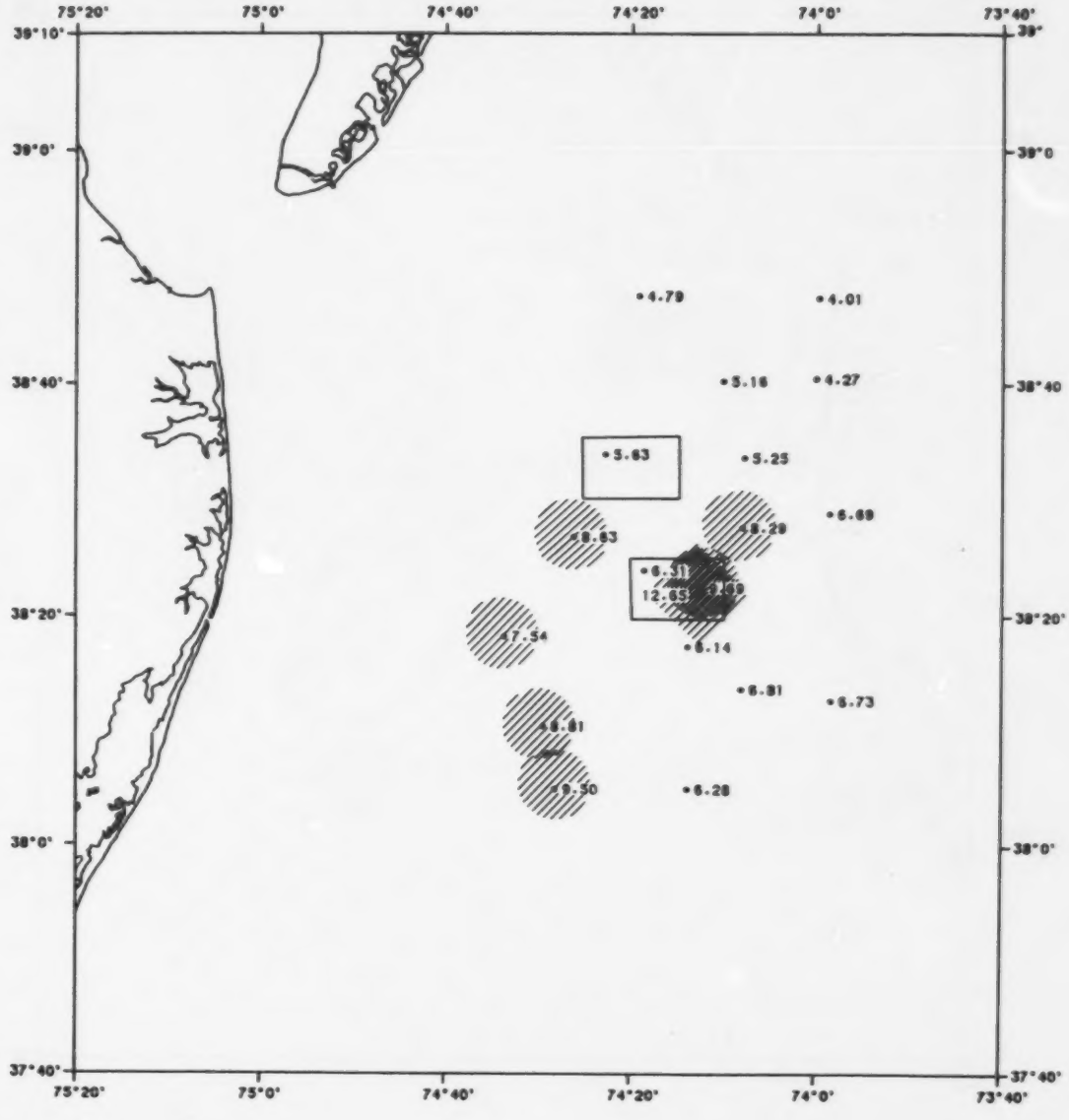

Figure 8. Mean Copper Concentrations in Whole Animal Scallop Samples for the March 1974 Cruise.

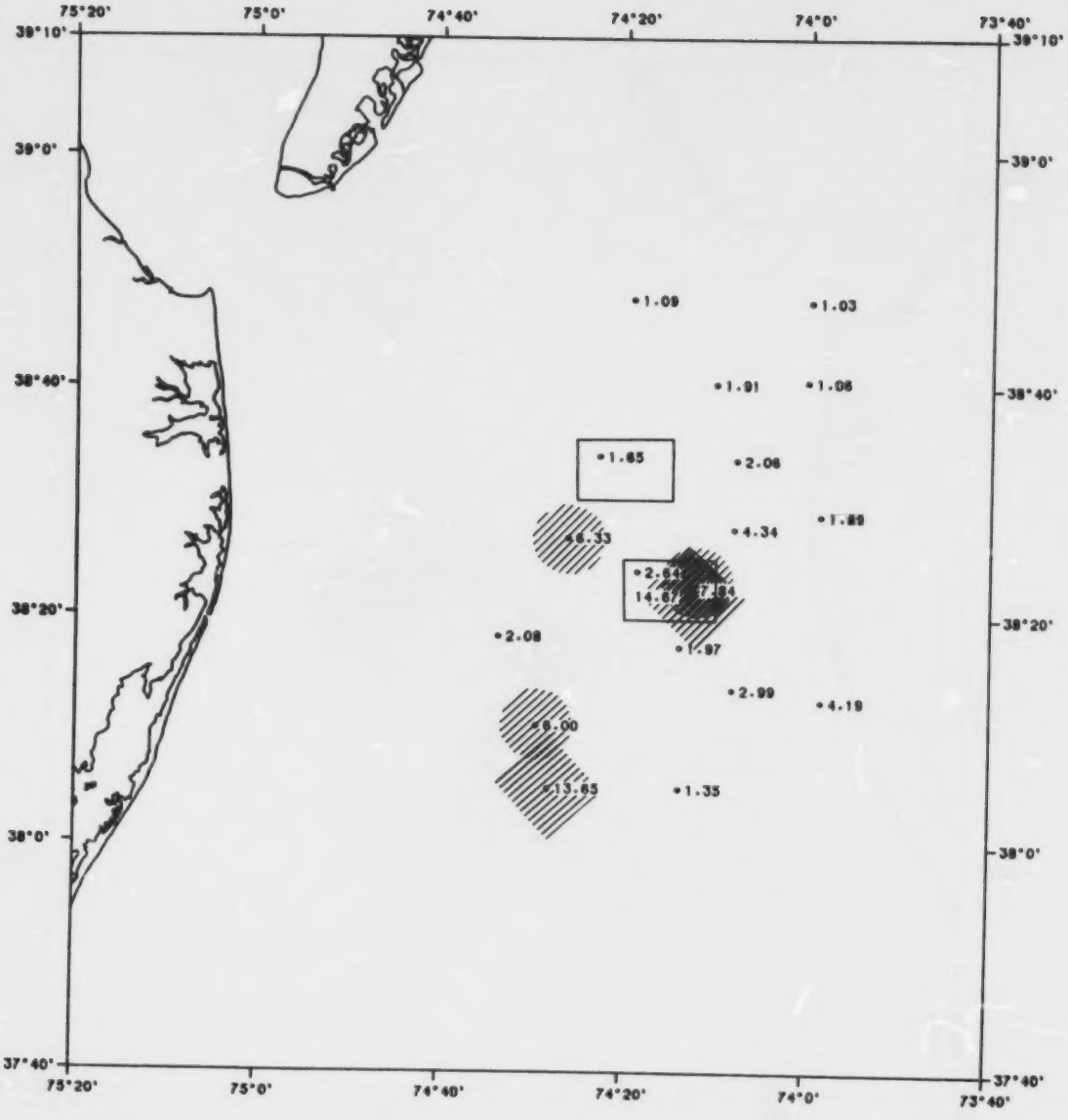

Figure 9. Mean Nickel Concentrations in Whole Animal Scallop Samples for the March 1974 Cruise.

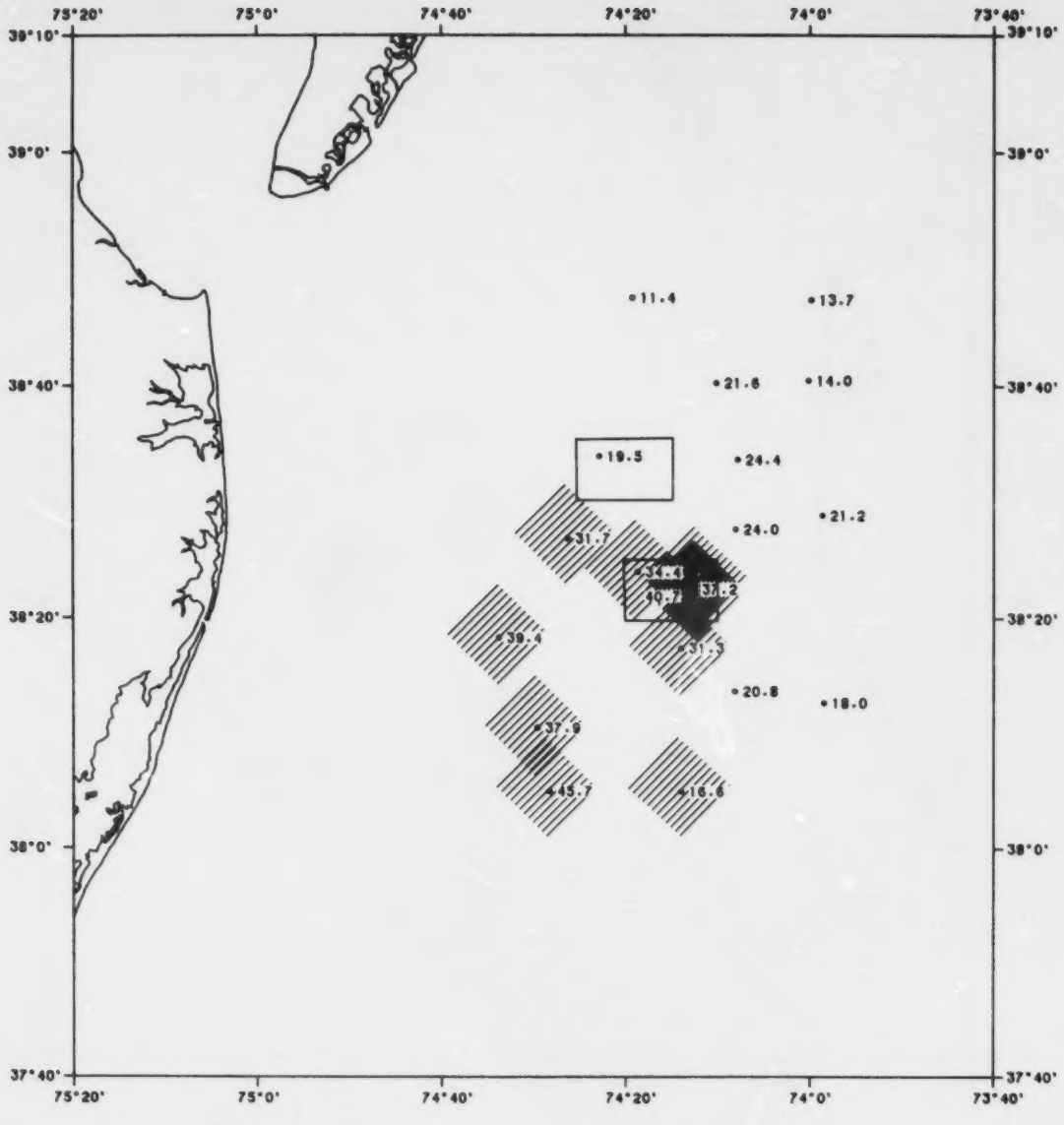

Figure 10. Mean Vanadium Concentrations in Whole Animal Scallop Samples for the March 1974 Cruise.

In an attempt to elucidate further the pathways of the waste material through the biological system, it was decided to perform separate statistical tests on the adductor muscles (the edible portion) and the viscera fractions of the scallop. In this revised procedure, where a station or group of stations had been previously defined as having significantly high metal concentrations in the whole animal, now the specific fraction, muscle or viscera, contributing to that high value is identified. The results of the analyses of variance are summarized in Table 3.

TABLE 3. SUMMARY OF ANALYSES OF VARIANCE OF Placopecten magellanicus DATA

Cruise		Sample	Metal			
			Cd	Cu	Ni	V
March	1974	M	0	X	0	0
		V	X	0	X	X
August	1974	M	X	X	0	0
		V	X	*	*	*
February	1975	M	0	*	0	0
		V	X	0	X	X
June	1975	M	X	X	0	0

0 No significant variation of metal concentrations at the .01 confidence level.
X Significant variation with an overlapping Duncan's subset of highest concentrations.
* Significant variation with an exclusive Duncan's subset of highest concentrations.
M Adductor muscle fraction of animal.
V Viscera fraction of the animal.

The geographical location of those stations having the highest metal concentrations, according to the previously described interpretation of the Duncan's tests, are presented in Figs. 11-18 as variously crosshatched areas. These are composite presentations of the data for all four cruises showing each of the four metals and the two tissue fractions.

TABLE 4. LEGEND: FIGURES 11 THROUGH 22

March 1974 Cruise

August 1974 Cruise

February 1975 Cruise

June 1975 Cruise

Stations which have the significantly highest concentrations; i.e., those which belong to the highest Duncan's subset. In this case, the highest subset does not overlap a lower subset.

Stations which have the significantly highest concentrations; i.e. those which belong to the highest Duncan's subset in cases where a wholly exclusive highest subset does not occur. In the case above, where a wholly exclusive subset does occur, the circled stations are those belonging to the second highest subset. In either case, the circled stations are those which are not included in ther overlapping portion of the subset. (Compare each figure with the corresponding table in the Appendix.)

Stations which have detectable concentrations, but cannot be tested for significance (Figures 15 and 17 only).

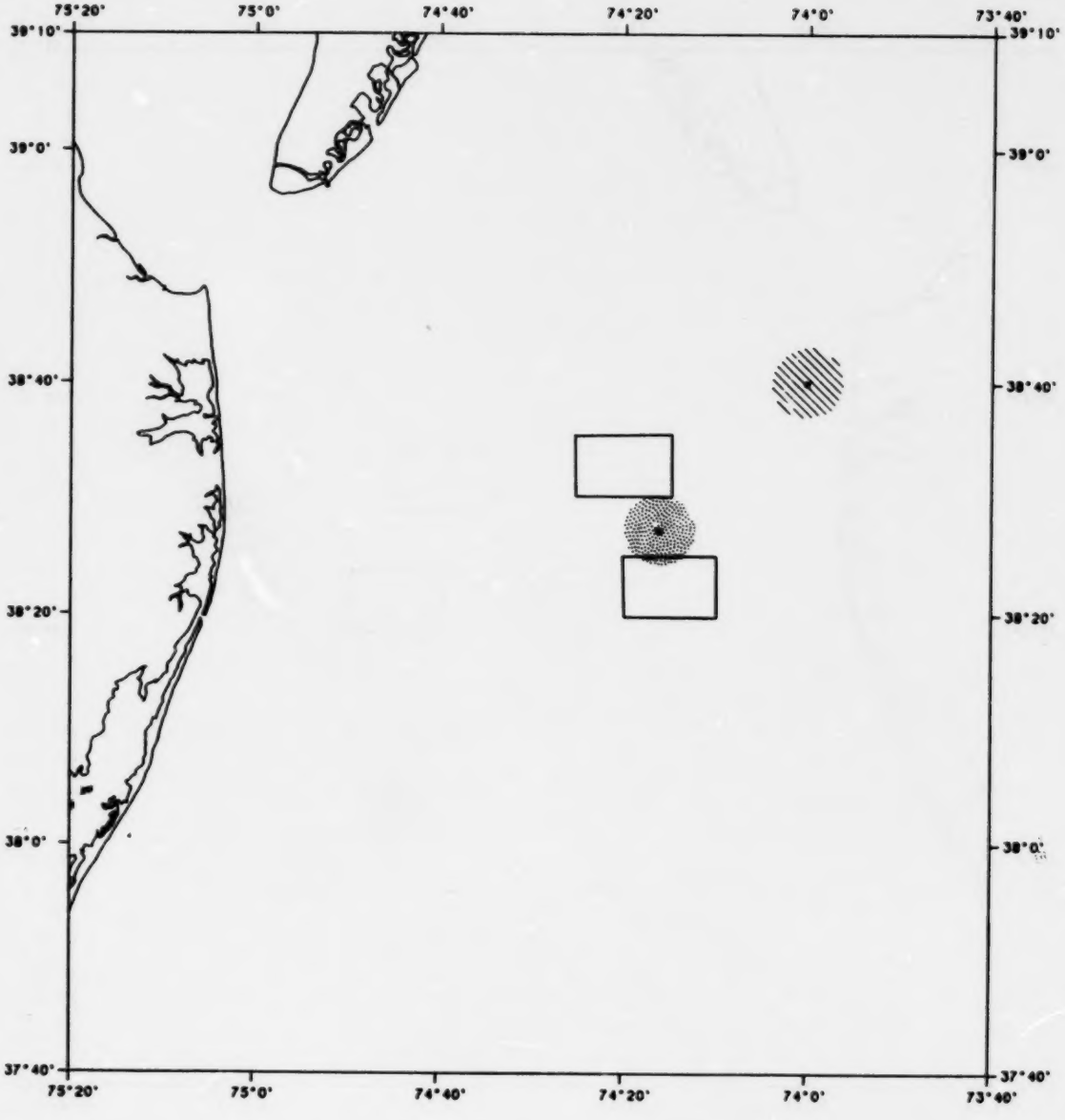

Figure 11. Significantly High Cadmium Levels in Scallop Muscle Samples.

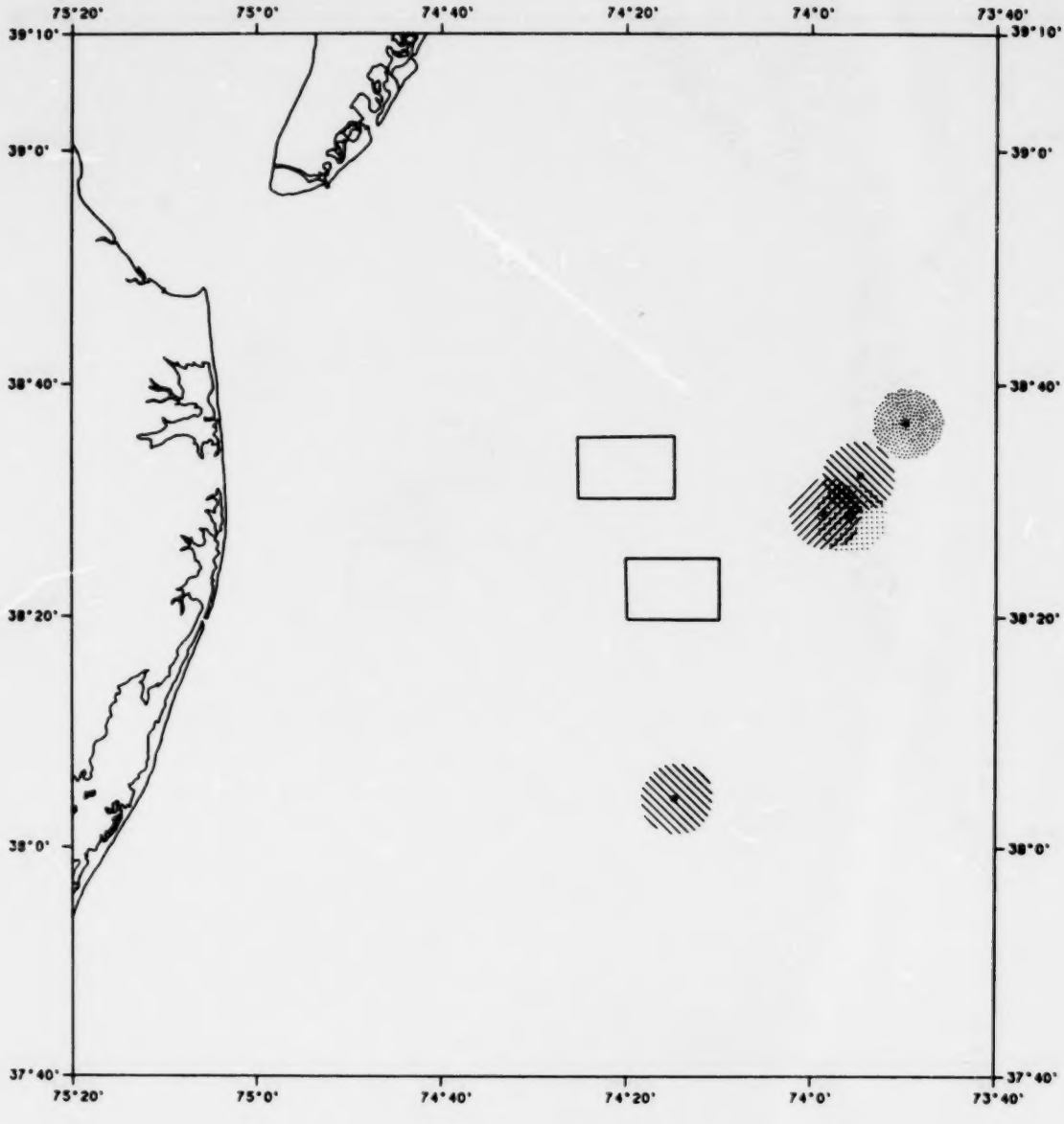

Figure 12. Significantly High Cadmium Levels in Scallop Viscera Samples.

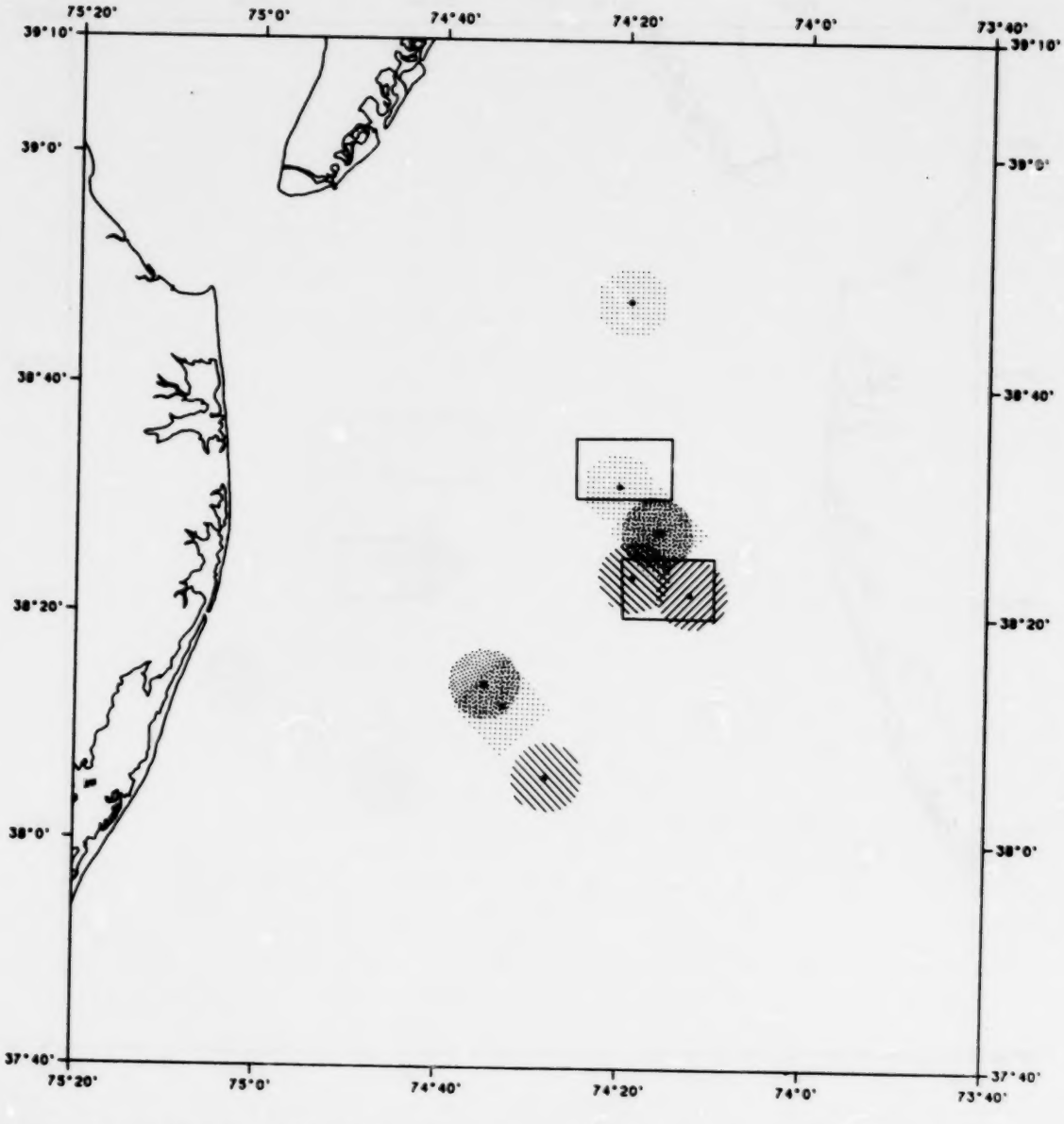

Figure 13. Significantly High Copper Levels in Scallop Muscle Samples.

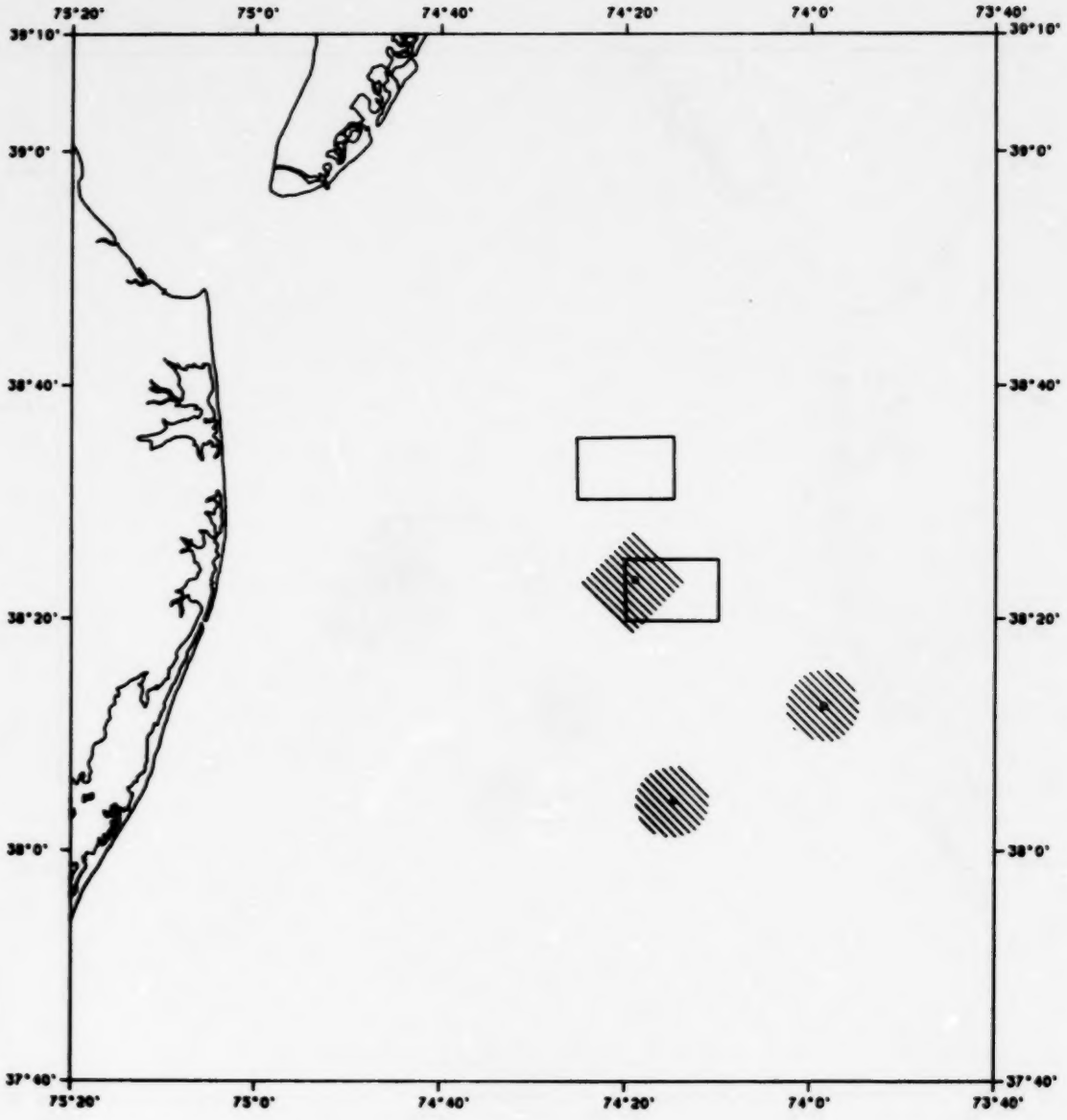

Figure 14. Significantly High Copper Levels in Scallop Viscera Samples.

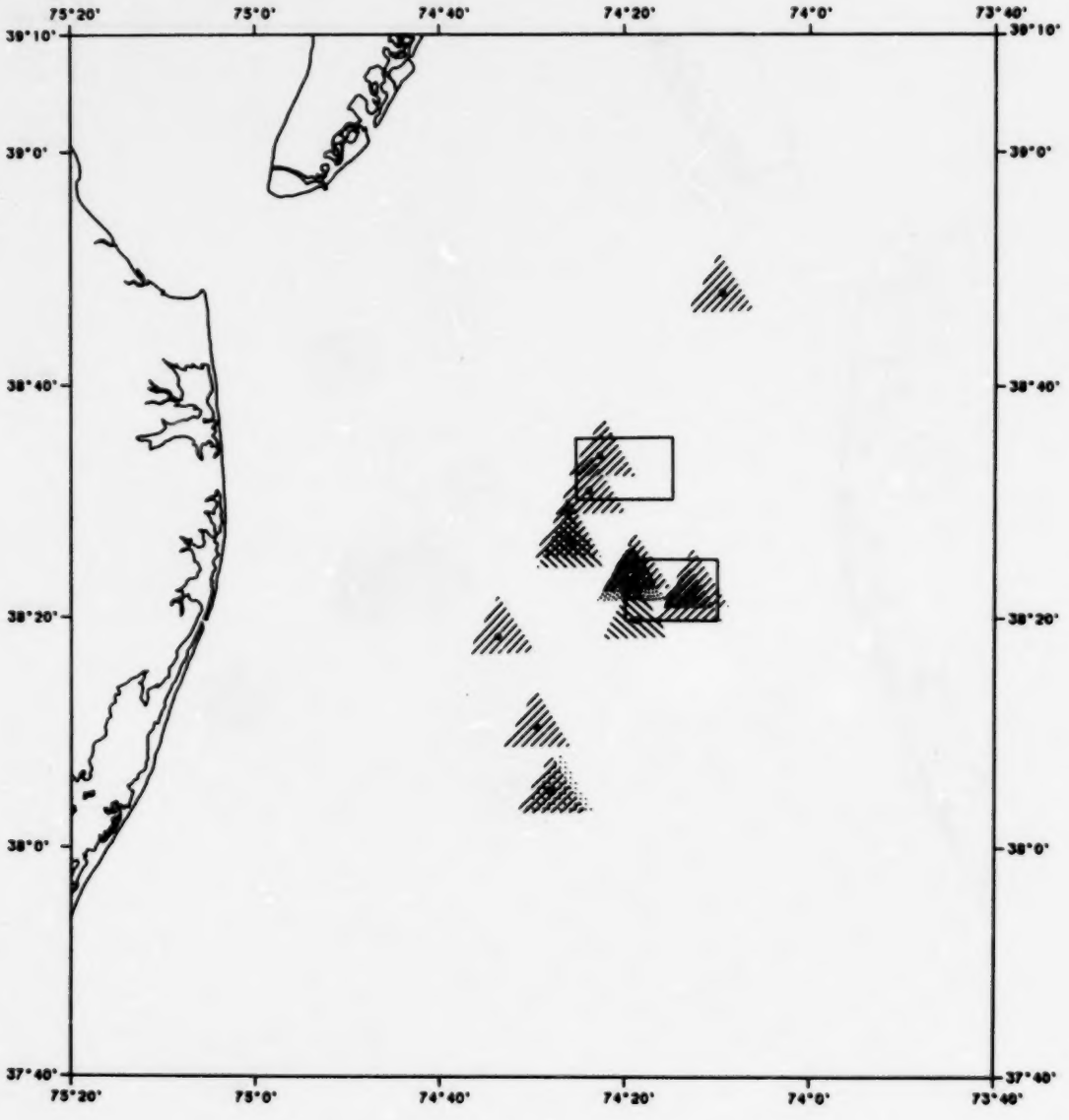

Figure 15. Detectable Nickel Levels in Scallop Muscle Samples.

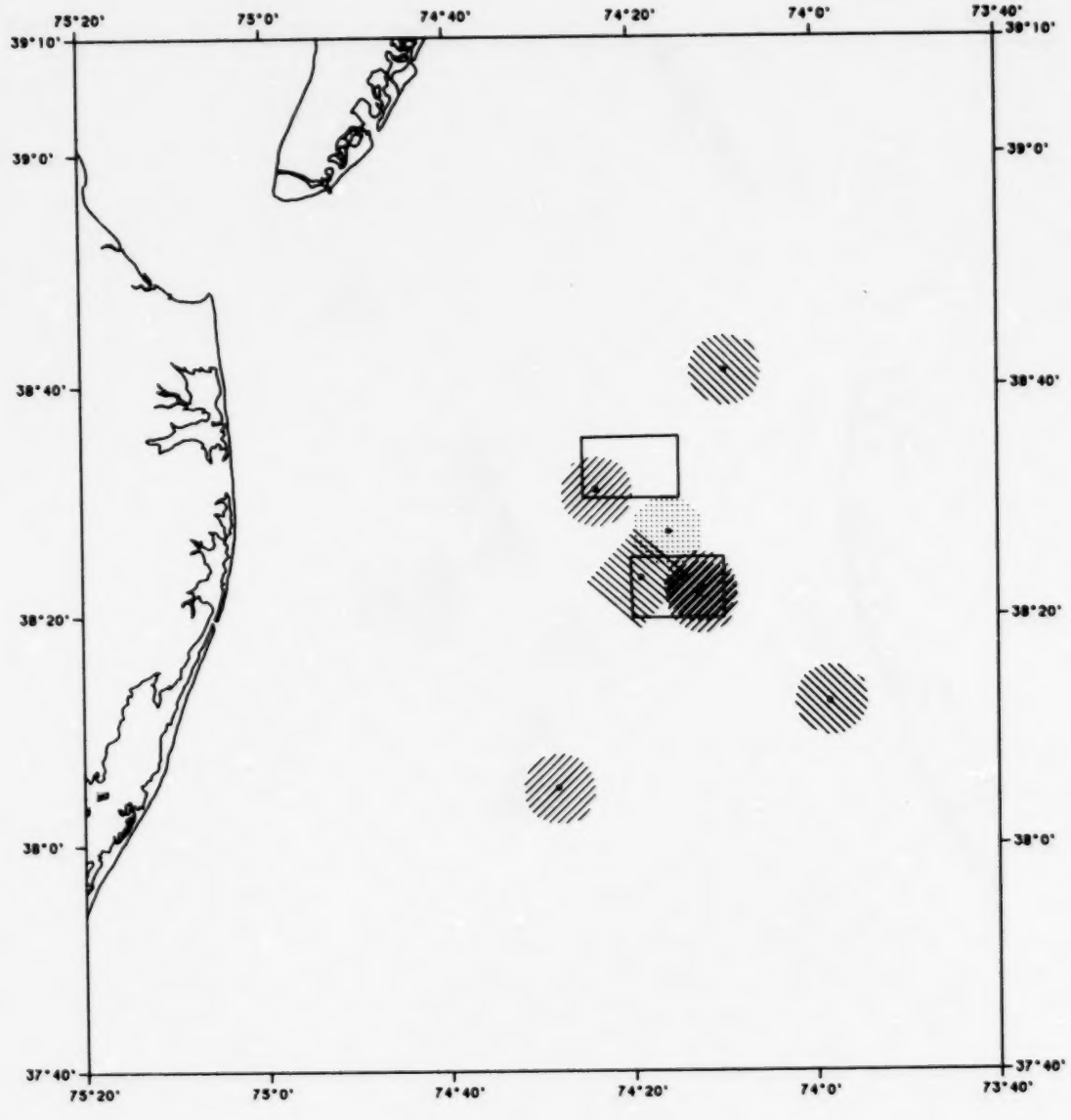

Figure 16. Significantly High Nickel Levels in Scallop Viscera Samples.

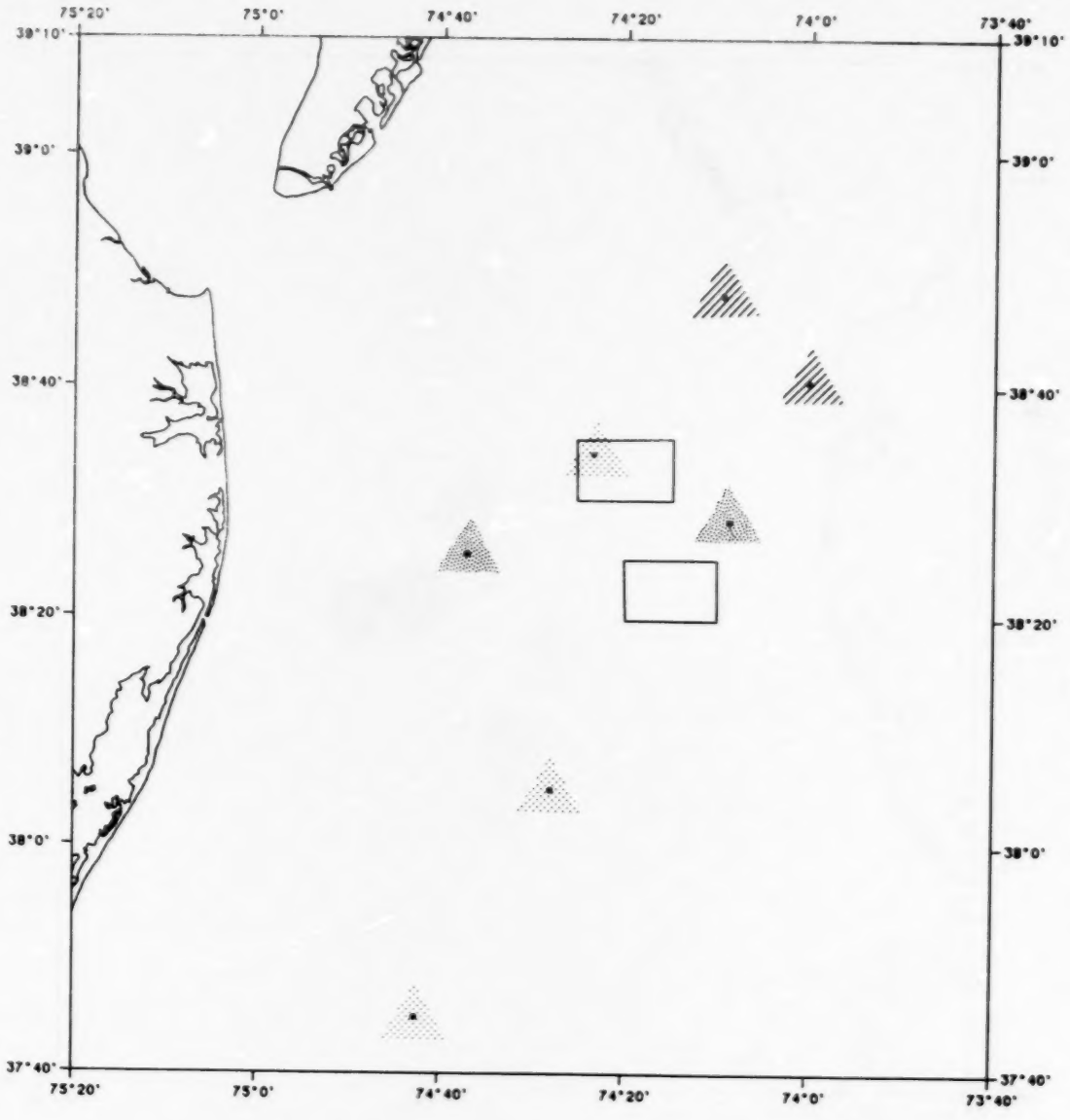

Figure 17. Detectable Vanadium Levels in Scallop Muscle Samples.

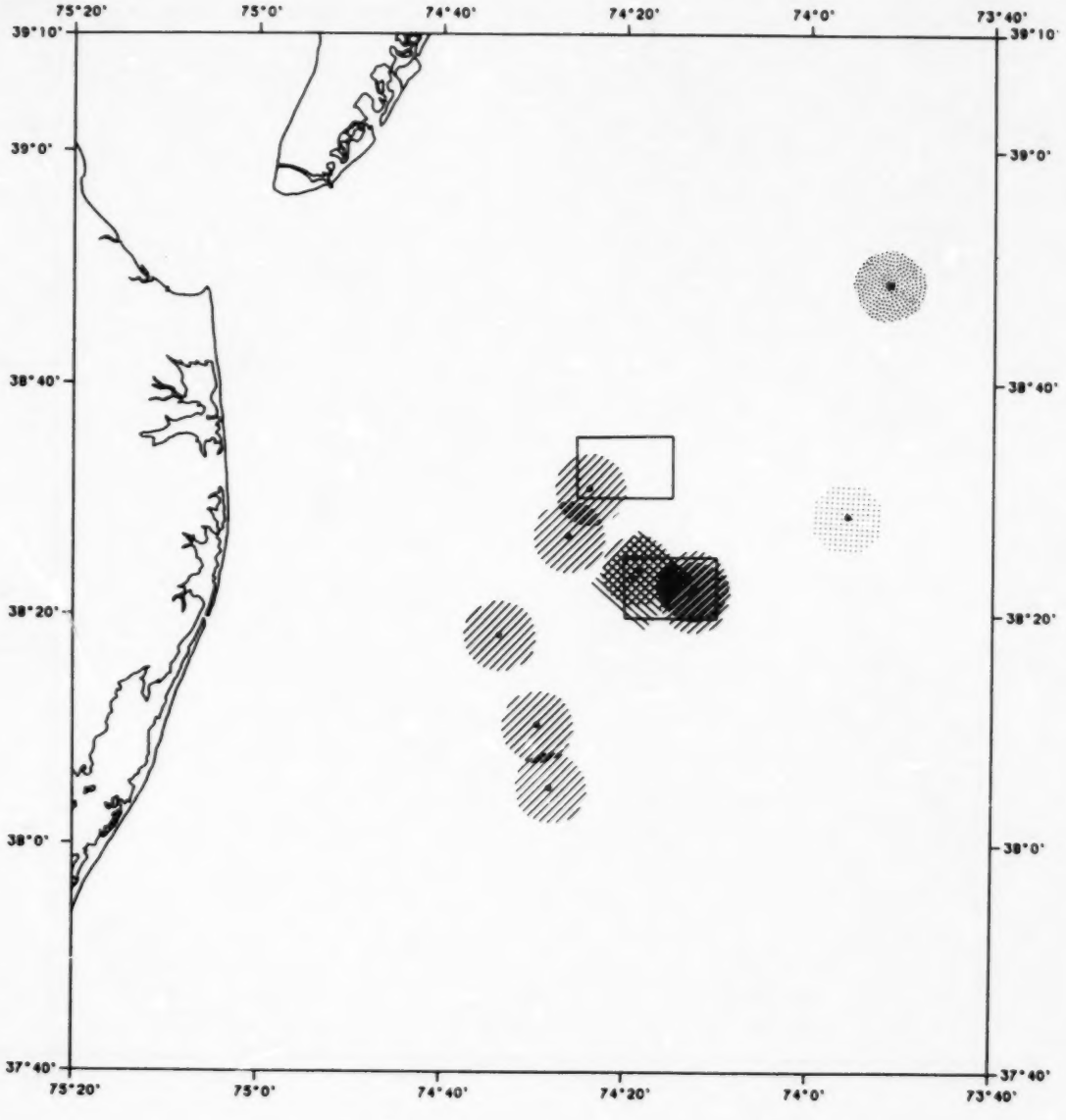

Figure 18. Significantly High Vanadium Levels in Scallop Viscera Samples.

Arctica islandica (ocean or mahogany quahog)

The analytical procedure for the ocean quahog followed the same course as that outlined for the scallop, with the exception that each specimen was digested and analysed whole rather than being separated into muscle and viscera fractions. The same constraints were applied to the use and interpretation of the Duncan's Multiple Range test. Again the four metals selected for appropriateness were cadmium, copper, nickel and vanadium.

The results are presented in Figs. 19-22 following the same format as for the scallop data. Table 5 summarizes the results of the analyses of variance for each of the four cruises and for each of the four metals.

TABLE 5. SUMMARY OF ANALYSES OF VARIANCE OF Arctica islandica DATA

Cruise		Metal			
		Cd	Cu	Ni	V
March	1974	X	X	O	*
February	1974	X	X	X	X
August	1975	X	X	*	O
June	1975	X	X	X	O

O No significant variation of metal concentrations at the .01 confidence level.
X Significant variation with an overlapping Duncan's subset of highest concentrations.
* Significant variation with an exclusive Duncan's subset of highest concentrations.

Refer to legend on page 18.

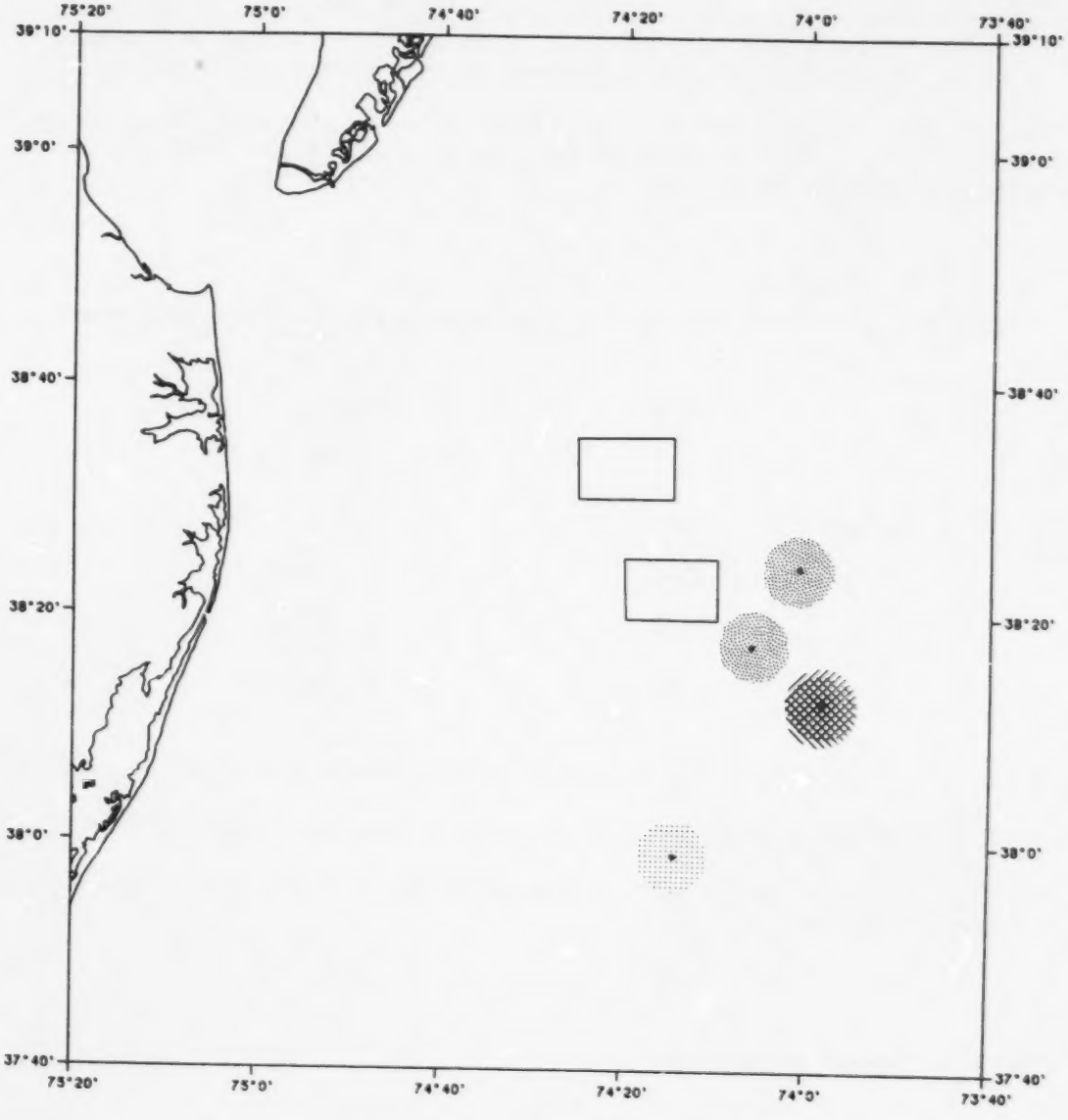

Figure 19. Significantly High Cadmium Levels in Ocean Quahog Samples.

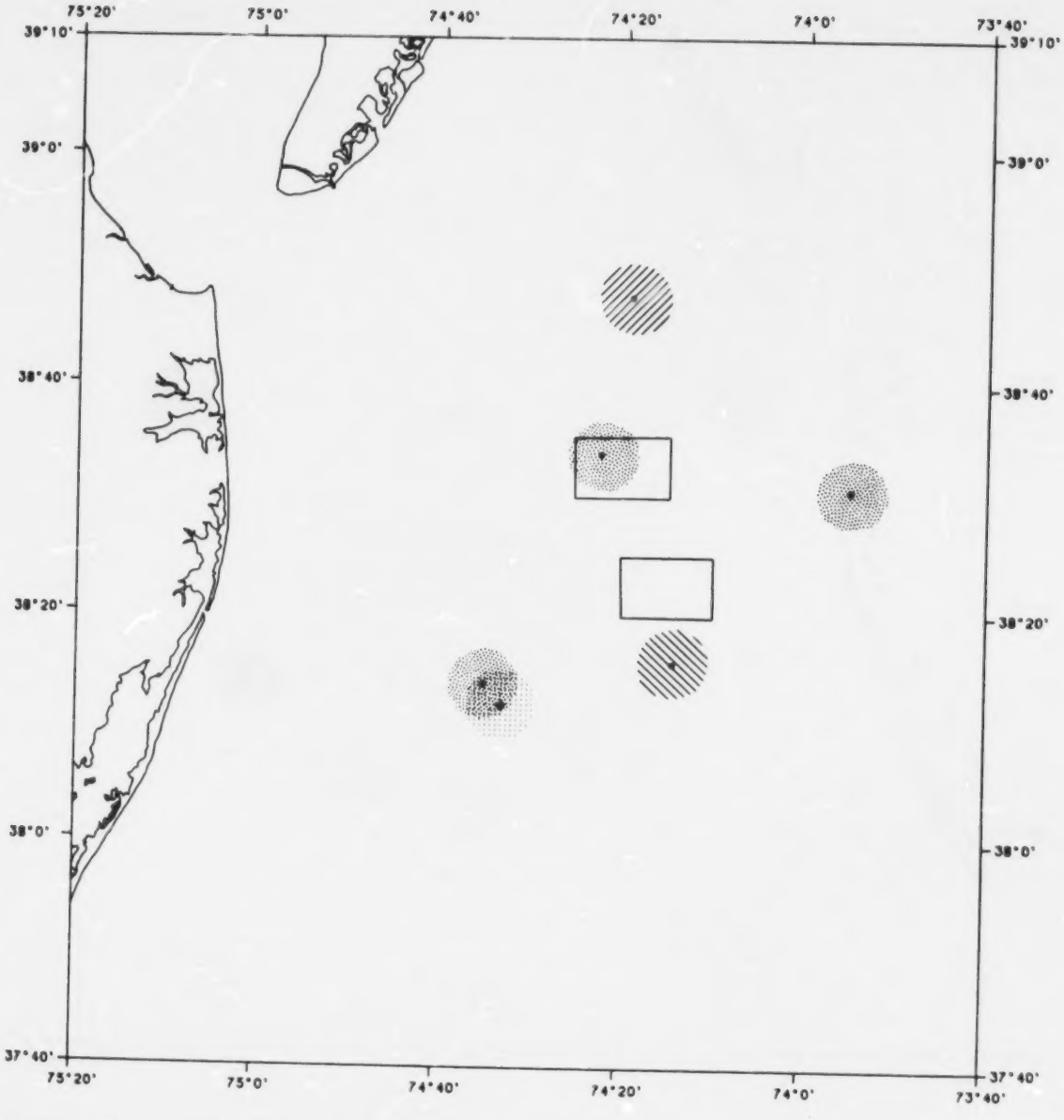

Figure 20. Significantly High Copper Levels in Ocean Quahog Samples.

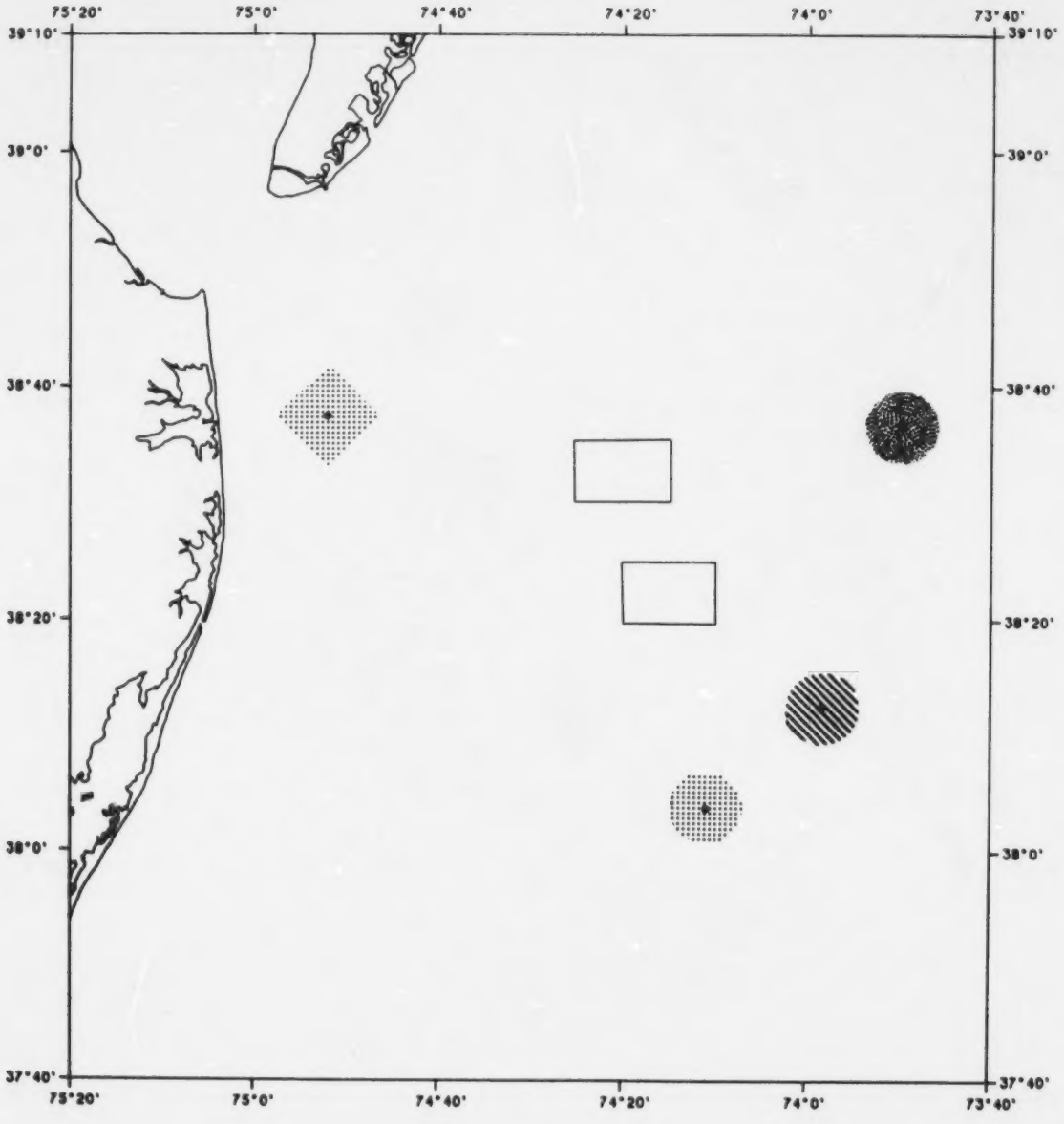

Figure 21. Significantly High Nickel Levels in Ocean Quahog Samples.

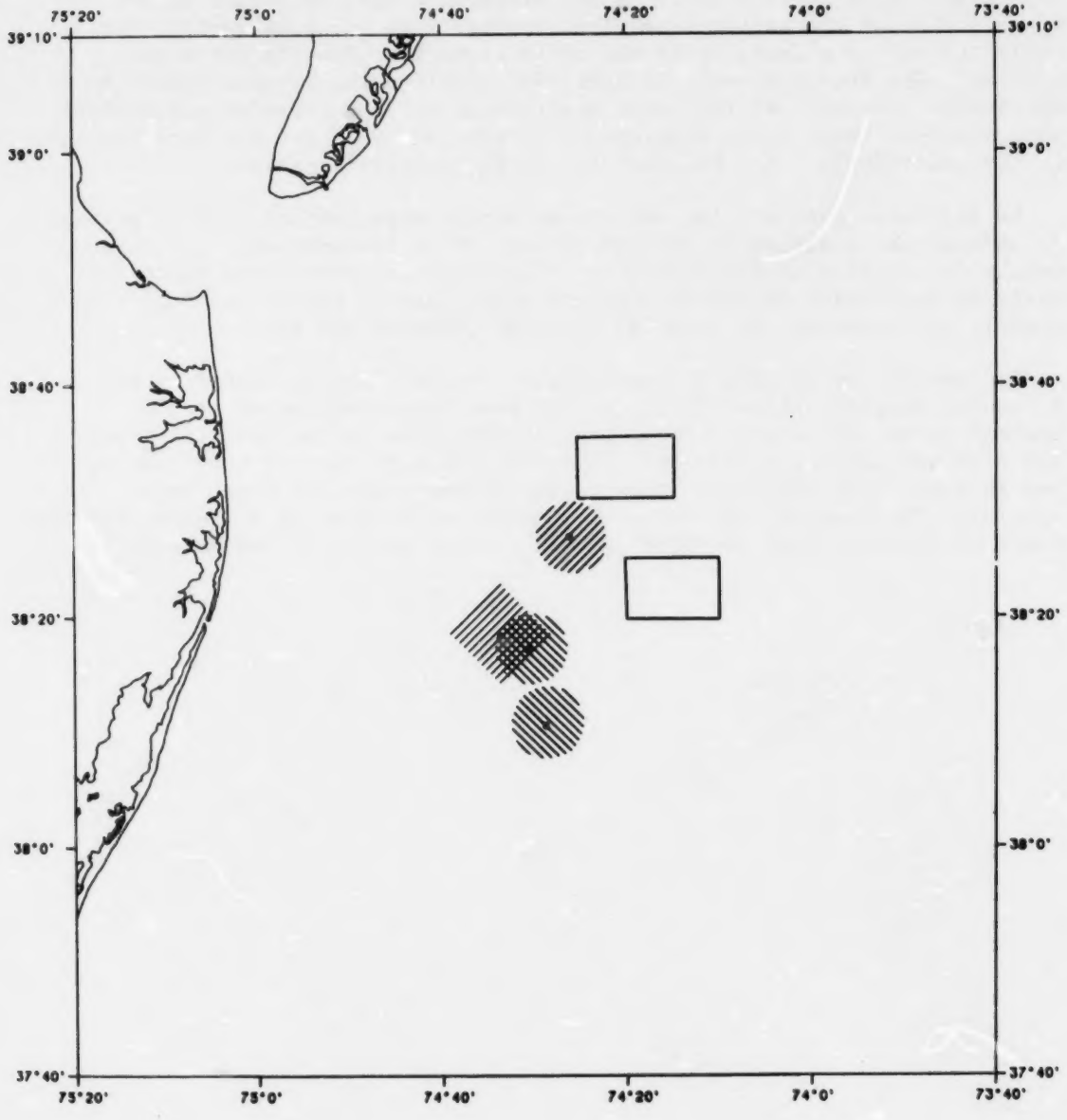

Figure 22. Significantly High Vanadium Levels in Ocean Quahog Samples.

Spisula solidissima (surf clam)

This species of shellfish has a greater shoreward and lesser oceanward distribution than either Placopecten or Arctica. Although of commercial importance along certain areas of the Atlantic coast, it occurs rather sporadically in the Delaware-Maryland coastal area and consequently was collected only incidentally to the collections made for the other two species. The fourth cruise, in June 1975, yielded the largest number of specimens. However, of the seven stations at which successful collections were obtained, only three stations, G12, G26, and G36, yielded more than one or two individuals. See Figure 5 (p. 8) for station locations.

In any case, analyses for six tracer metals were conducted in an attempt to address the question of the possibility of an inshore source of these metals in addition to the dumpsites. The metals selected were those four analyzed previously in the scallop and ocean quahog, namely cadmium, copper, nickel, and vanadium, with the addition of chromium and zinc.

Because of the paucity of individuals, the data are presented in the following diagrams (Figs. 23-28) as the mean concentration or single concentration (horizontal line), the concentration range (vertical line), and plus and minus one standard deviation (vertical bar), rather than as Duncan's Multiple Range test results as presented for the other two species. The stations are arranged in order of increasing distance from the mouth of Delaware Bay, the hypothesized inshore source of the metals.

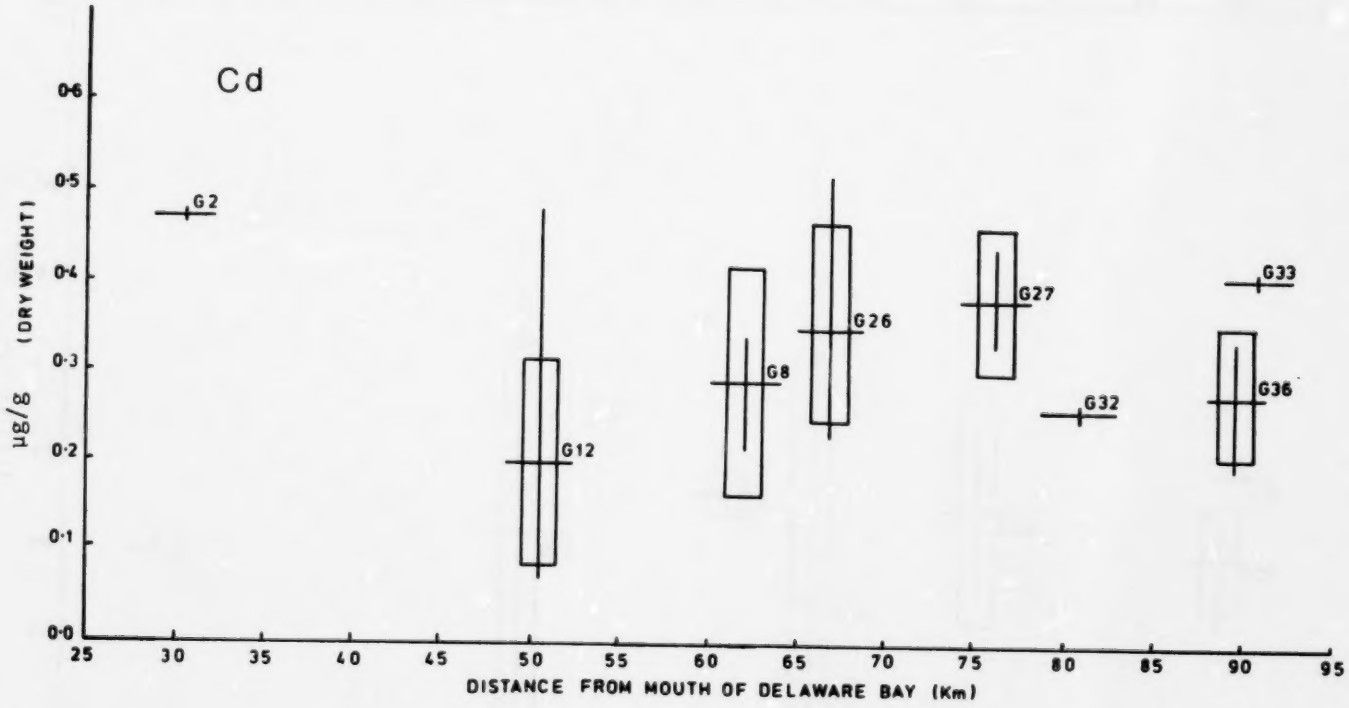

Figure 23. Cadmium Levels in Spisula for the June 1975 Cruise.

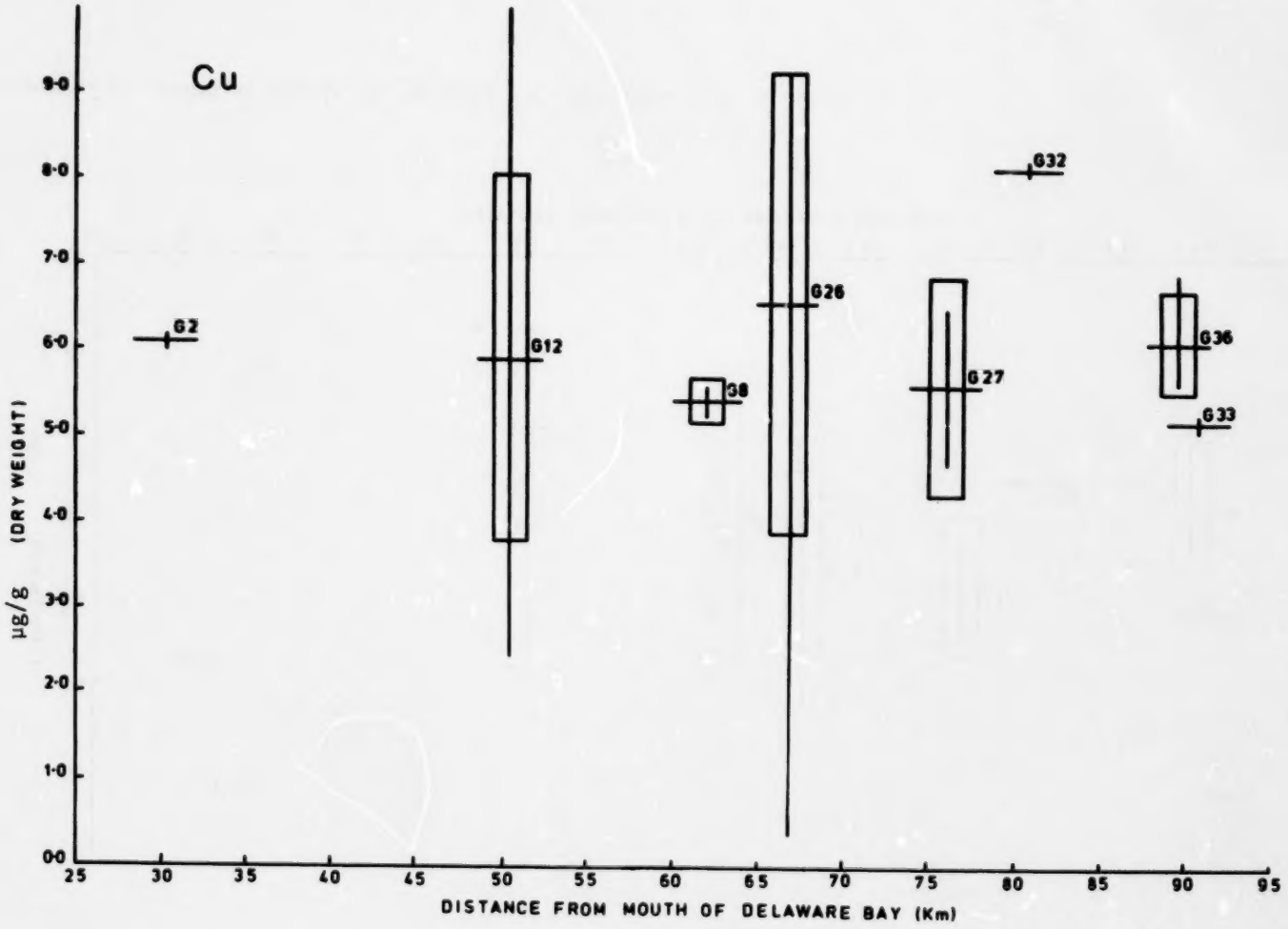

Figure 24. Copper Levels in Spisula for the June 1975 Cruise.

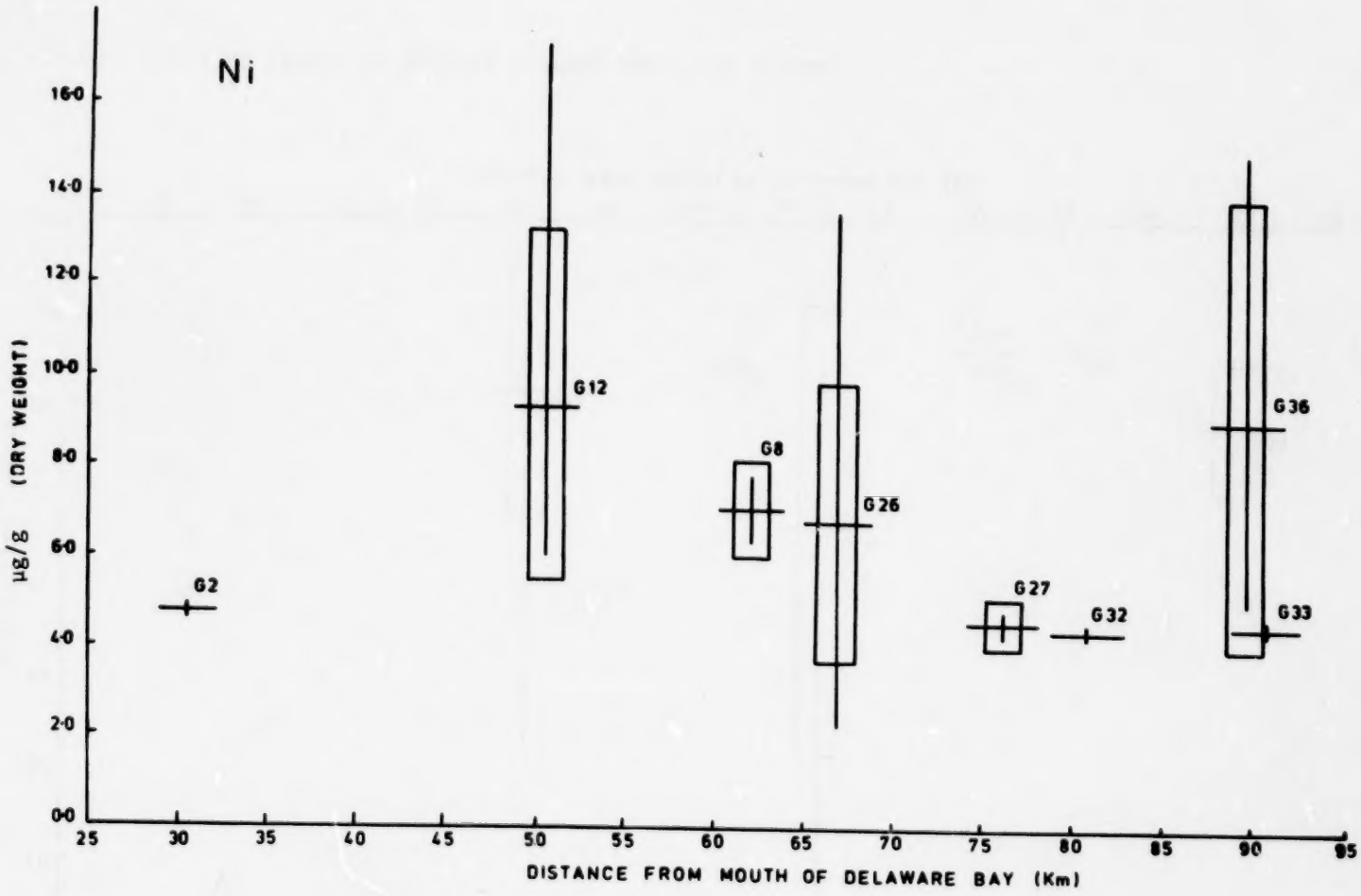

Figure 25. Nickel Levels in Spisula for the June 1975 Cruise.

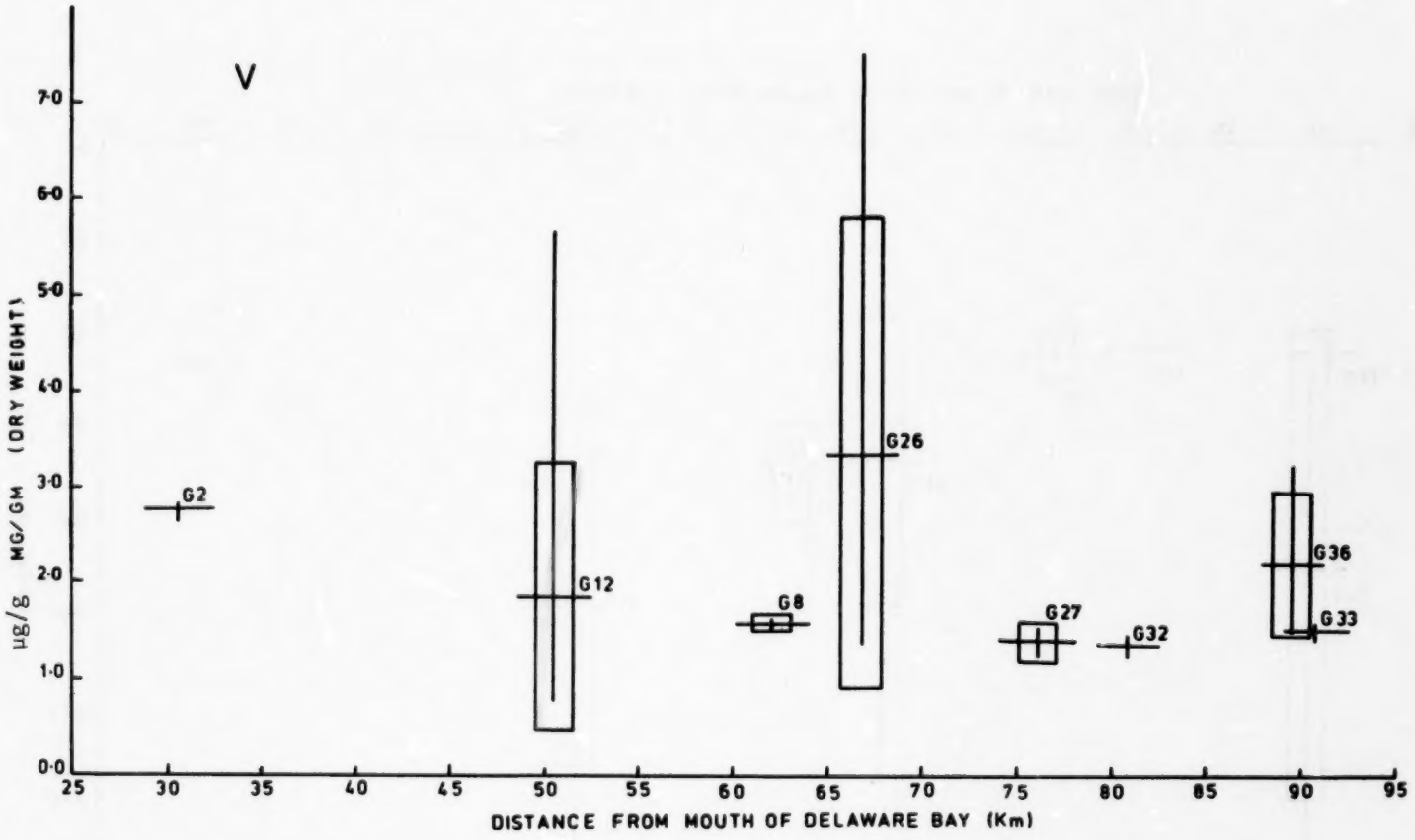

Figure 26. Vanadium Levels in Spisula for the June 1975 Cruise.

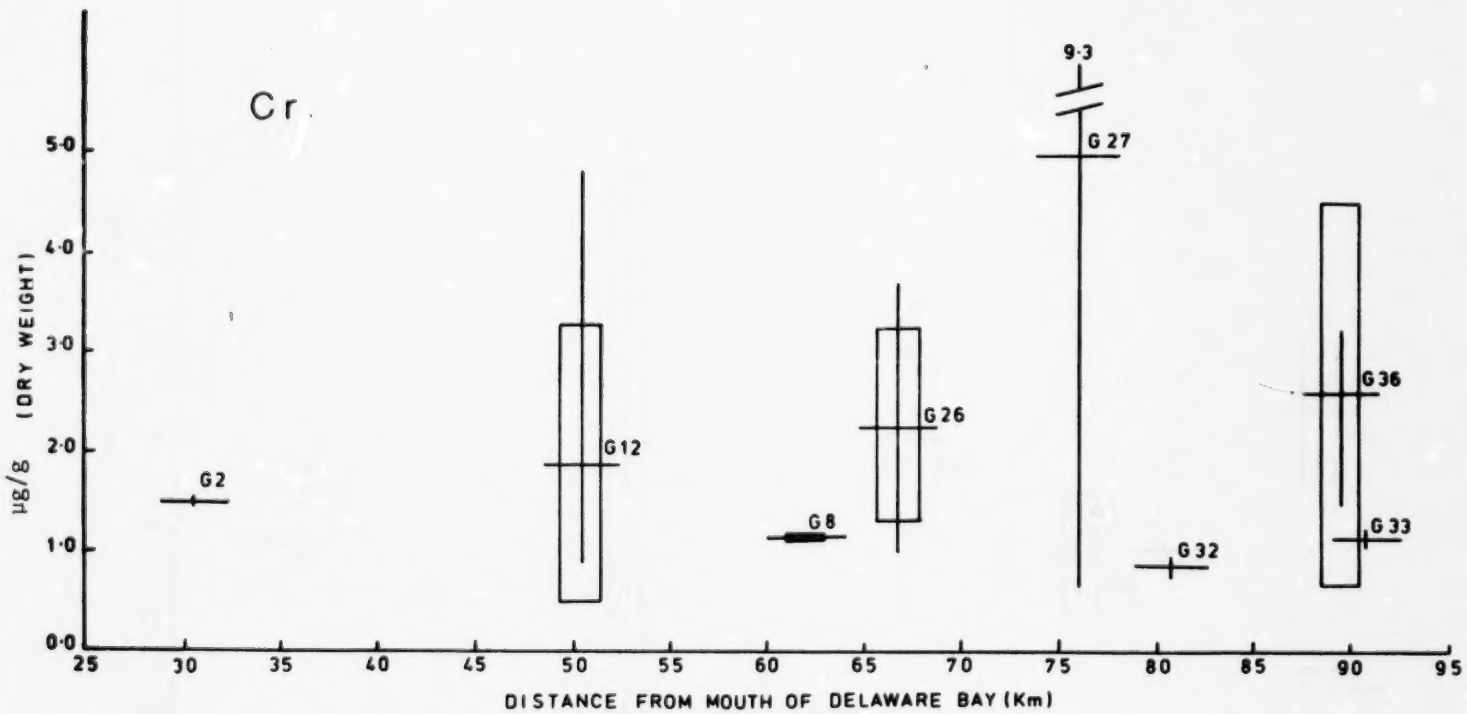

Figure 27. Chromium Levels in Spisula for the June 1975 Cruise.

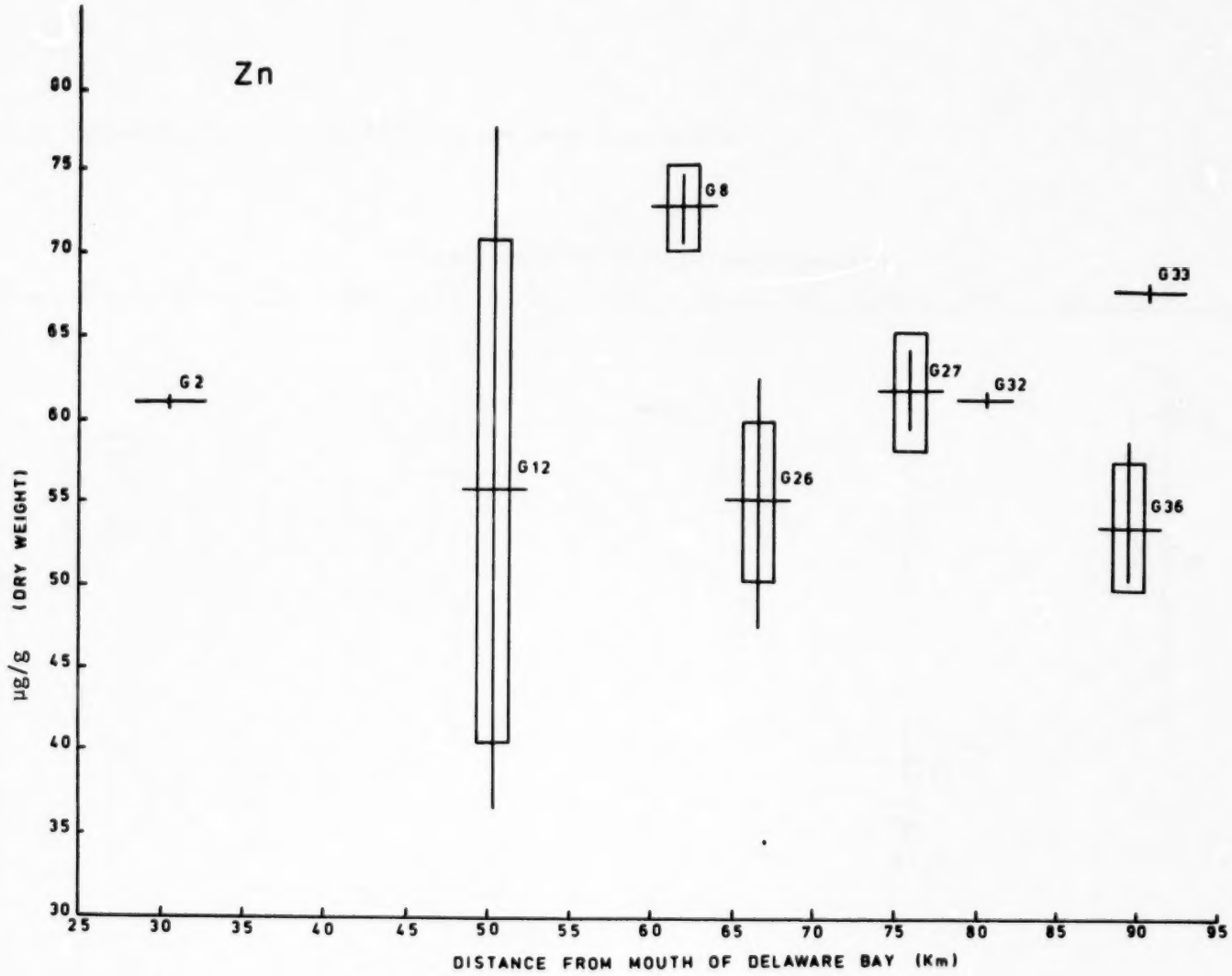

Figure 28. Zinc Levels in Spisula for the June 1975 Cruise.

SECTION 4

DISCUSSION

Elevated metal concentrations have been detected at many marine sites exposed to acid wastes or sewage sludge. Acid wastes from a titanium dioxide factory near Bremerhaven have been disposed in the German Bight since May 1969, (Weichart, 1972). Five and a half months after beginning disposal, elevated iron concentrations in seawater samples were found in an area of about 515 km^2. Since autumn 1969, ferric hydroxide floc has been found on the bottom. In areas well removed from this dumpsite in the direction of expected transport, there were indications of iron uptake in the soft tissues of the filter-feeding bivalve, Venus gallina L. (Rachor, 1972). Since 1948, a similar acid waste from titanium dioxide production by N.L. Industries has been disposed in New York Bight. In 1970, a study by Vaccaro et al. (1972) described findings of a brown, flocculent, particulate material, probably ferric hydroxide floc, on the bottom of the acid waste disposal site. Elevated metal concentrations in zooplankton, benthos, and sediments were also detected.

Large quantities of other waste materials from the New York metropolitan area have been disposed in the New York Bight for nearly a century. Carmody et al. (1973), studying the distribution of metals in sediments in and around the dredge spoil and sewage sludge sites, found two central regions of high concentration and zones of elevated metal concentrations extending 30 km southeast and 12 km northeast of the disposal sites. Distribution of coliform bacteria and organic matter correlated well with that of the metals. Areas affected by sewage sludge were found to be "devoid of normal benthic populations" (Pearce, 1972).

Similar studies have been conducted in the Thames estuary where London sludge has been disposed since 1887. Shelton (1971) found elevated zinc, lead, and copper levels in organic muds sampled in the vicinity of the disposal site. Mackay and Topping (1970) described studies in the Firth of Clyde where the city of Glasgow had disposed its sewage sludge since 1904. They reported preliminary findings of elevated metal concentrations in sediments within the disposal area. Further studies by Mackay et al. (1972) confirmed and extended the earlier findings to include observations of high metal concentrations in animals within the disposal area.

More recently, studies by Klemas et al. (1978) at the acid waste site off the coast of Delaware have contributed significantly to the understanding of the behavior of oceanic currents in the study area.

Using current drogues equipped with radio transmitter buoys, surface, mid-depth, and bottom currents were tracked over periods of up to several days. The results of the study showed a general tendency for oceanic currents to flow toward the southwest. The most rapid currents, 1 to 1 1/2 knots, appeared to be derived from storms which, in this area, consist mainly of strong northeast winds. During the presence of a thermocline however, the surface waters were observed to depart from the general pattern of southwest flow and flow toward the north and northeast.

The translocation of waste materials, as a result of these oceanic currents, is clearly demonstrated by LANDSAT photographs of the area. Figures 29 and 30 are two of the many satellite photographs available which encompass the study area and show the acid waste plume. The outlines of the two disposal sites have been superimposed on the photographs for illustration purposes. Figure 29 shows a plume of acid waste 14 hours and 47 minutes after disposal took place. The waste plume appears as the cloudy area oriented in a northwest-southeast direction immediately adjacent to the southwest corner of the acid waste site. Figure 30 shows a waste plume, still in its recognizable "pretzel" or "bow tie" configuration, moving out of the acid waste site toward the southeast. Klemas et al. (1978) reports similar behavior for the majority of the plumes thus photographed.

Corresponding photographs of the sewage sludge plumes are not available since this waste does not possess sufficient contrast with respect to the water to be photographed. However, given the large scale of the current patterns, the sludge would be expected to behave in a manner similar to the acid waste. Differences would be attributable to a differential dispersion of the wastes with depth and a concurrent presence of current shears with depth. During two cruises conducted since the period of this report, visual observations of sewage sludge disposal observations showed a similar behavior observations showed a similar behavior to that of the acid waste in that the sludge plumes were carried by surface currents out of the disposal site and with little lateral dispersion.

It is obvious, therefore, that translocation of the acid wastes out of the disposal sites occurs with regularity. Moreover, the acid waste plumes persist visually and more or less intact for several hours after the disposal operation. Consequently, the metals contained in the wastes are potentially available in significant concentrations for uptake by marine organisms living quite far for the boundaries of the disposal sites.

Figure 29. LANDSAT Photograph, 20 April 1974, 14 hrs. 47 min. after disposal at the Acid Waste Site.

Figure 30. LANDSAT Photograph, 24 February 1976, 9 hrs. 10 min. after disposal at the Acid Waste Site.

Placopecten magellanicus

Cadmium

Results of analyses for cadmium in the viscera of the scallop samples (Fig. 12) show a consistently recurring pattern in the distribution of stations having significantly high concentrations of the metal for each of the four cruises. A definite cluster is seen in an area located between, but to the east of the two disposal sites, directly on the thirty fathom line. The wide spacing of collecting stations and patchy distribution of organisms, however, does not permit a further examination of the actual areal extent and homogeneity of this cluster and others described. Those stations defined by the Duncan's tests as having significantly higher levels of cadmium in the muscle portion of the scallop are limited to the second and fourth cruises (Fig. 11). One is located directly between the disposal sites (August 1974), while the other is to the north and east. In this case, the higher concentrations are located mid-way between the twenty and thirty fathom line. These differences in locations of stations having high concentrations of cadmium in muscle and viscera tissues may provide an interesting tool for interpretation, since cadmium present in the adductor muscle reflects true bioaccumulation or assimilation of the metal into the tissue itself, while cadmium in the viscera of the animal may reflect the presence of the metal in any form in the digestive tract, in addition to possible bioaccumulation by the digestive organ tissue. This latter situation implies an immediately available source but does not necessarily suggest a long term effect unless assimilation can be established. The former situation suggests the converse.

Copper

Copper was bioconcentrated to significantly higher levels in the muscle of the scallop in several stations identified by the Duncan's Multiple Range test. In the March, 1974 cruise, a single station was identified within the boundaries of the Philadelphia disposal site. The August, 1974 data revealed a second station having higher concentrations within the disposal site as well as another to the south and west of the sewage sludge site. For the February 1975 cruise, those stations having higher concentrations of copper in the muscle of the scallop were found once again to the southwest of the sewage sludge disposal site. New areas of elevated levels were also found more to the north, just outside the sewage sludge site and within the acid waste site. A fourth station was located well to the north of the acid waste site. Results from the June 1975 cruise show stations with elevated levels just north of the sewage sludge site but between the two disposal areas and one, once again, to the southwest. As seen cumulatively (Figs. 13&14) these stations form a broad congregation of points between the twenty and thirty fathom lines, centered within or just to the north of the sewage sludge site and extending toward the south and west. This distribution is also parallel to the oscillatory northeasterly-southwesterly bottom currents generally recognized to prevail throughout this area of the continental shelf (Callaway, 1975).

Nickel

As may be observed from the results of the appropriate Duncan's tests, the distribution of stations having high concentrations in the viscera, if viewed collectively (Fig. 16), show a pattern similar to that observed for copper in the scallop muscle tissue, in which consistently high concentrations were found within or immediately to the north of the sewage sludge site with a scattering of other locations ranging northeasterly/southwesterly from the site. This again parallels the current regime described for the area (Callaway, 1975). The obvious exception to this is the lack of any statistically significant nickel concentrations found for the most recent (June 1975) cruise.

Vanadium

The scallop viscera results from the March 1974 cruise show a group of seven stations having significantly high vanadium concentrations clustered in and around both disposal sites and extending to the southwest between the twenty and thirty fathom contours. However, the three cruises since that date show only a single station each. The August 1974 cruise revealed one station within the sewage sludge disposal area; the February 1975 cruise showed one between the two disposal sites, but toward the east on the thirty fathom line; and the final cruise produced a single station well to the north and east of the area of disposal activity, between the twenty and thirty fathom line. Moreover, a comparison of the mean metal concentrations show a general decline since the first cruise, particularly among the stations defined as significantly high. Analyses of the muscle fractions for vanadium have shown consistently very low values, most of which are below the detection limit, leading to the possible hypothesis that what vanadium is present in the environment, as shown by visceral uptake, is not readily assimilated by the adductor muscle tissue.

Arctica islandica

Cadmium

Stations highest in cadmium contained in the total soft tissues of the ocean quahog were found directly to the east and southeast of the sewage sludge site. Although the specific location varies from cruise to cruise, these higher stations appear consistently between the thirty and forty fathom contours. The wide spacing of sampling stations employed to cover an increasingly large area of the continental shelf with each subsequent cruise and the discontinuous distribution of the organisms throughout the area thwarted our efforts to more closely define these areas of observed high concentrations. As a check of the analytical precision of the data, the results were compared with those of Rogerson and Galloway. In the latter study, a homogenate of 637 Arctica was prepared and analyzed in 65 replicate aliquots. The variation among replicates was such that the standard deviation was within 6% of the mean for the same 4 metals. Since this measure of variation among animals at a given station in the present study was typically 20 to 80% of the mean and since homogenization of animals analyzed individually is not a factor, the analytical results may be considered to be

sufficiently precise.

Copper

Copper concentrations in the ocean quahog collected on the four cruises do not display a reoccurring distribution of significantly high values as observed for cadmium, nor the clustering of high values immediately adjacent to the disposal sites as observed for the copper concentrations in the scallop. Since there is apparently sufficient copper potentially available in the environment as evidenced by the scallop data, this scattering of areas of high concentration for the ocean quahog may perhaps be attributable to interspecific differences in feeding habit, motility or metabolic utilization of the metal, or perhaps differential speciation of the metal itself. In any case, there is little obvious association of uptake of this metal by the ocean quahog with the disposal activities.

Nickel

Although the distribution of nickel concentrations in ocean quahog samples do not form a consistently reoccurring pattern, for the three most recent cruises for which the data show a locally high concentration each, these stations lie in a zone coincident with that observed for the distribution of cadmium concentrations, i.e. offshore of the dumpsite area and between the thirty and forty fathom contours. In addition, the highest value observed for any of the four cruises was the 29.3 ppm. observed at the February 1975 cruise station M-5. While the sample size of only three individuals was less than ideal, it was the only successful catch of Arctica in this area. In any case, the high value possibly may be attributable to the close proximity of this station to the mouth of Delaware Bay. However, since nickel is a characteristic component of the sewage sludge and since station M-5 is located only a few kilometers south of a disposal site used by Philadelphia prior to moving to the present site in May 1973, a causal relationship is suggested.

Vanadium

Vanadium, selected as a tag or tracer for the acid waste, failed to show significantly high concentrations in the tissues of the ocean quahog after the cruise in August 1974. On the two earlier cruises, however, elevated vanadium concentrations were observed directly southwest of the acid waste site, along the twenty fathom contour and in the direction of prevailing bottom currents.

Additional treatment of the scallop and quahog data addressed the question of metal concentration as a possible function of animal weight, and hence age. The results of a regression analysis performed on the metal concentration and animal weight data indicated a positive correlation of metal concentration with animal weight. However, a comparison of animal weights among stations indicated that no station, identified as having significantly high metal concentrations, was biased due to a correspondingly high abundance of large animals. The higher metal concentrations are therefore interpreted as reflecting a higher, although probably sporadic, degree of ex-

posure of the animal to the waste materials at those locations.

It would be quite desirable, at this point, to do a time series analysis of the data in order to examine possible changes in metal levels in animals between cruises. This is impossible, however, due to a number of factors. In an attempt to expand the area of examination from one cruise to the next, not all stations were consistently reoccupied. More importantly, however, for those stations which were reoccupied, the catch of shellfish fluctuated greatly, sometimes yielding no specimens at all. As a result of this variation, a suitable data base was not available to support the statistical requirements of a time series analysis.

In general, however, a comparison of the present data with that of Rogerson and Galloway shows that all of the samples collected in the vicinity of the two disposal sites contain metal levels considerably above what might be expected in a relatively clean marine environment; in this case, Block Island Sound. Specifically, the present disposal site study shows the lowest levels for Cd, Cu, Ni, and V in the ocean quahog to be 1.06, 4.44, 3.05, and 1.26 ppm dry weight respectively. The Rogerson and Galloway study showed corresponding concentrations of 0.01, 0.07, 0.06, and 0.05 ppm in the Block Island Sound collection of Arctica.

Spisula solidissima

A visual examination of the surf clam data (Figs. 23-28) show that the concentrations of each metal appear to fall roughly within equivalent ranges regardless of station. There are no marked increases or decreases in concentration with distance from the mouth of Delaware Bay. As a check, a regression analysis was performed on the nickel data. The results showed no trend toward higher or lower values either inshore or offshore. However, since the variation among concentrations at a given station often exceeded the variation between stations, and with the relatively small amount of data available in this study there could be no demonstration of a source of enrichment for heavy metals shoreward of the disposal sites. Thus, the surf clam did not serve as a useful test organism for tracing the impact of the waste materials.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The disposal sites in this study are geographically isolated from anthropogenic influences other than the barged wastes. Consequently, it may reasonably be assumed that the barged wastes are the dominant source of any high concentrations of anthropogenic metals. These metals, being non-degradable, may be used therefore as tracers of those wastes since the metal compositions of both waste materials themselves have been well characterized. The fact that these tag metals are found in significantly elevated concentrations in scallops and quahogs, sampled from areas of expected waste transport from the dumpsite, indicates clearly that the metals-laden liquid wastes reach the bottom communities as these mid-shelf depths and that the metals themselves are biologically available, not only within the limits of the dumpsites themselves but, in many cases, far beyond and that their distribution is determined to a great extent by the prevailing current regime.

While a greater degree of success in catching large samples of animals from a great number of reoccupied stations over a longer period of time would add to a more detailed knowledge of the impact and fate of the two types of waste materials, it is nevertheless quite apparent that the designated dumpsites can be considered as no more than discharge sites rather than containment sites for these liquid wastes. In the case of the metals attributable to the sewage sludge, the rapid onset of bioaccumulation over a wide area is evidenced by the patterns of elevated concentrations which occurred by the time of the first cruise, within a period of only ten months after the initiation of dumping.

Additional hydrographic and biochemical studies, both short term to ascertain in detail the fate of a specific waste plume, and long term to assess net regional distribution patterns and zones of accumulation both in animals and in sediments, would lead to a more thorough understanding of the pathways of the waste materials or its fractions into and through the benthic ecosystem. Similarly, knowledge regarding the chemical speciation of the various metals in seawater, i.e., dissolved, chelated, aggregated, etc., would contribute to a more detailed understanding of the apparent different behavior among those metals. The fact remains, however, that because of this demonstrated biological availability of metals and their known toxic properties (Eisler, 1973; Eisler, et al. 1975; Eisler et al., 1978; Anon. 1972) the metals contained in these wastes pose a threat to the biota of this portion of the continental shelf, in spite of the large dilutions involved in this mode of disposal. It would appear that continued research is warranted if ocean disposal of wastes on the continental shelf is to be continued.

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APPENDIX A

ANALYTICAL RESULTS

The raw data used to prepare Figures 11 through 22 are presented in the following tables. Tables 5-12 present the mean concentrations and Duncan's subsets of each of the four metals for each station for the four cruises in the scallop muscle tissue (Tables 5, 7, 9, and 11) and in the scallop viscera (Tables 6, 8, 10, and 12). Tables 13-16 present similar data for Arctica islandica.

LEGEND

n number of samples

$\bar{x}$ mean metal concentration

D Duncan's subset. Those stations bounded by a vertical line (a subset) are not significantly different from each other.

Sta Cruise station number

Except: In Tables 9 and 11 where many of the results were below the analytical detection limits, as indicated by N.D. in the $\bar{x}$ column, the Duncan tests could not be performed and the number listed in parentheses in the D column are the number of samples at those stations which were above the detection limit.

TABLE A-1. MEAN CADMIUM CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP MUSCLE SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
9	8.78	T	14	10	2.64	T	19	1	3.54	T	26	2	3.69	T	D
4	5.16	|	27	3	2.08	|	28	2	3.29	|	C	2	2.83	|	G29
5	4.01	|	19	10	2.06	|	25	8	3.20	|	F	2	2.66	|	G19
4	2.20	|	F	9	2.02	|	14	9	3.16	|	14	10	2.55	|	G20
1	1.97	|	23	10	1.84	|	27	2	2.16	|	30	6	2.49	|	G10
9	1.74	|	8	4	1.48	|	21	10	2.15	|	23	12	2.48	|	G25
6	1.67	|	24	3	1.46	|	E	1	1.93	|	20	2	2.46	|	G27
2	1.55	|	20	2	1.35	|	18	10	1.77	|	27	2	2.30	|	G47
4	1.32	|	18	2	1.19	|	26	1	1.67	|	D	6	2.11	|	G14
3	0.90	|	28	7	1.18	|	F	10	1.64	|	T14	2	2.00	|	G22
3	0.84	|	30	2	1.00	|	33	4	1.49	|	E	5	1.80	|	G32
1	0.69	|	29	2	0.98	|	9	10	1.46	|	24	2	1.69	|	G24
8	0.64	|	17	10	0.87	|	22	1	1.42	|	28	2	1.51	|	G53
10	0.60	|	22	1	0.85	|	20	7	1.36	|	8	10	1.39	|	G34
4	0.57	|	E	9	0.72	|	17	10	1.17	|	2	21	1.36	|	G54
1	0.56	|	21	3	0.70	|	8	9	1.02	|	22	6	1.16	|	G38
3	0.53	|	9	2	0.68	|	B	5	1.00	|	29	1	1.09	|	G5
2	0.46	|	2	1	0.51	|	A	1	0.74	|	A	2	0.99	|	G37
1	0.40	|	8	1	0.49	|	29			|		2	0.66	|	G42
				9	0.46	|	24								

TABLE A-2. MEAN CADMIUM CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP VISCERA SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
7	104.1		14	10	121.2		27	9	161.8		14	10	105.3		G20
4	86.4		27	10	115.7		14	1	119.5		26	2	94.1		G29
4	66.9		19	10	109.0		25	10	98.1		27	6	80.6		G10
2	39.5		25	10	88.6		19	2	95.9		30	14	71.7		G25
3	38.9		30	4	59.5		8	10	89.4		23	7	63.0		G14
10	38.7		F	3	53.8		E	10	74.2		F	2	49.2		G42
10	36.6		24	7	50.4		F	9	55.5		T14	10	45.0		G34
6	30.7		23	10	49.0		24	5	50.0		29	7	44.0		G38
3	28.0		9	10	45.0		21	10	47.1		22	22	42.9		G54
1	27.0		29	3	41.2		18	1	38.6		20	2	38.6		G19
1	26.0		B	2	38.6		9	4	37.6		E	2	36.9		G47
6	25.9		26	1	38.4		20	10	34.6		24	1	33.7		G5
10	24.6		22	2	37.4		B	7	31.5		8	2	32.0		G22
9	24.4		17	7	36.8		17	1	30.8		A	2	27.7		G53
4	20.6		21	1	35.6		A	9	30.3		2	2	25.2		G27
12	20.2		E	9	33.4		22	2	25.8		C	2	25.1		G24
8	19.3		18	5	33.3		33	3	24.5		28	2	24.6		G37
10	18.5		8	3	32.5		C	1	19.5		D	2	19.5		D
5	17.6		2	1	30.6		29	1	16.1		9	13	19.3		G32
2	17.3		20	3	29.2		26								
3	16.0		28	4	26.5		28								

TABLE A-3. MEAN COPPER CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP MUSCLE SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
5	14.84	I	2	3	4.42	I	E	2	6.60	I	D	2	2.57	I	D
4	8.98	I	26	3	4.32	I	26	1	5.65	I	9	12	2.23	I	G32
9	6.01	I	8	3	2.57	I	C	2	3.40	I	C	2	1.87	I	G27
10	4.42	I	22	9	2.20	I	21	3	3.26	I	28	2	1.77	I	G19
8	4.11	I	17	10	2.04	I	22	10	2.32	I	F	14	1.74	I	G25
1	4.10	I	8	3	1.98	I	18	10	1.83	I	T14	2	1.59	I	G37
2	3.62	I	20	5	1.72	I	33	10	1.76	I	2	2	1.51	I	G24
6	3.31	I	23	3	1.71	I	28	7	1.74	I	8	2	1.48	I	G53
2	2.23	I	25	10	1.44	I	25	4	1.67	I	E	22	1.29	I	G54
9	2.04	I	14	3	1.41	I	8	1	1.54	I	20	10	1.29	I	G34
4	1.80	I	27	7	1.33	I	F	10	1.44	I	24	2	1.26	I	G29
8	1.80	I	18	10	1.14	I	27	2	1.43	I	30	7	1.24	I	G14
10	1.74	I	F	1	1.10	I	A	9	1.35	I	14	7	1.23	I	G38
5	1.54	I	19	10	1.03	I	24	10	1.30	I	23	1	1.21	I	G5
10	1.52	I	24	9	0.99	I	14	10	1.30	I	27	2	1.21	I	G22
4	1.43	I	21	1	0.97	I	29	1	1.29	I	A	6	1.12	I	G10
12	1.26	I	E	10	0.95	I	19	1	1.28	I	26	10	1.11	I	G20
3	1.23	I	28	1	0.93	I	20	5	1.27	I	29	2	1.05	I	G47
3	1.00	I	9	2	0.85	I	8	9	1.12	I	22	2	0.94	I	G42
3	0.95	I	30	2	0.80	I	9								
1	0.95	I	29	9	0.80	I	17								

TABLE A-4 MEAN COPPER CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP VISCERA SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
1	14.30		B	3	20.09		E	2	15.85		30	2	9.61		G42
10	12.74		8	10	12.72		25	1	14.16		26	10	9.59		G20
5	11.92		2	10	12.50		27	3	12.58		28	2	9.54		G53
9	11.84		17	10	11.79		14	10	12.10		22	22	9.54		G54
6	11.62		23	4	10.99		8	5	11.83		29	14	9.42		G25
10	11.60		22	4	10.56		28	10	11.79		27	7	9.36		G14
3	10.70		9	10	10.53		21	9	11.31		14	2	9.24		G47
7	10.63		14	9	10.47		22	1	11.28		9	7	9.16		G38
10	9.75		F	1	10.35		A	1	11.20		D	13	9.09		G32
12	9.72		E	3	10.35		18	7	10.75		8	2	9.01		G29
7	9.64		26	10	10.24		19	2	10.42		C	2	8.70		D
2	9.13		25	10	9.90		24	10	10.24		F	6	8.69		G10
4	9.12		27	1	9.54		29	4	10.12		E	2	8.58		G19
10	9.03		24	3	8.90		C	1	9.84		20	10	8.38		G34
4	7.86		19	7	8.75		F	1	9.39		A	1	8.35		G5
8	7.74		18	5	8.58		33	10	9.38		23	2	8.35		G37
3	7.24		28	3	8.30		26	9	8.70		T14	2	8.00		G24
1	7.15		29	2	8.29		9	9	8.69		2	2	7.29		G27
3	7.12		30	7	8.05		17	10	7.91		24	2	7.25		G22
4	7.07		21	2	8.04		8								
2	6.99		20	1	8.04		20								

TABLE A-5. MEAN NICKEL CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP MUSCLE SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
5	22.29	--	2	3	4.86	--	E	1	0.29	--	26	8	ND	(0)	G20
5	10.60	--	26	10	1.41	--	22	10	ND	(1)	2	14	ND	(0)	G25
9	8.40	--	8	3	0.75	--	8	7	ND	(2)	8	22	ND	(0)	G54
9	8.08	--	17	10	ND	(0)	24	1	ND	(0)	20	2	ND	(1)	G24
10	7.02	--	22	10	ND	(1)	25	4	ND	(0)	E	7	ND	(1)	G14
1	6.08	--	B	7	ND	(0)	F	1	ND	(0)	9	2	ND	(0)	G22
10	2.22	--	E	10	ND	(5)	27	2	ND	(0)	D	7	ND	(0)	G38
2	1.50	--	20	3	ND	(2)	26	10	ND	(3)	27	13	ND	(0)	G32
3	0.88	--	9	9	ND	(2)	17	10	ND	(2)	22	10	ND	(0)	G34
1	0.28	--	29	2	ND	(0)	9	2	ND	(1)	C	2	ND	(0)	G37
3	ND	(1)	28	5	ND	(1)	33	1	ND	(0)	A	2	ND	(0)	G42
8	ND	(6)	18	2	ND	(0)	8	2	ND	(0)	30	6	ND	(0)	G10
4	ND	(3)	21	1	ND	(0)	20	5	ND	(0)	29	2	ND	(0)	G27
6	ND	(4)	23	3	ND	(0)	C	3	ND	(0)	28	2	ND	(0)	G47
4	ND	(3)	27	9	ND	(0)	21	10	ND	(8)	F	1	ND	(0)	G5
5	ND	(4)	19	9	ND	(0)	14	9	ND	(4)	14	2	ND	(0)	G19
10	ND	(6)	24	10	ND	(0)	19	10	ND	(0)	23	2	ND	(0)	G20
2	ND	(1)	25	3	ND	(0)	18	10	ND	(0)	T14	2	ND	(0)	G53
3	ND	(2)	30	1	ND	(0)	A	10	ND	(0)	24	2	ND	(0)	G29
10	ND	(5)	F	3	ND	(0)	28					2	ND	(0)	D
9	ND	(4)	14	1	ND	(0)	29								

TABLE A-6. MEAN NICKEL CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP VISCERA SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
1	13.14		B	3	8.77		E	1	7.55		D	2	3.65		G32
5	10.78		2	2	4.39		18	10	4.46		F	1	2.65		G19
7	10.35		26	4	3.57		25	1	3.16		23	9	2.63		G34
10	8.08		8	9	2.96		22	9	3.05		14	7	2.51		G38
10	5.96		22	1	2.30		26	2	2.76		30	20	2.46		G54
9	5.96		17	10	2.16		27	10	2.60		22	1	2.46		G5
2	4.64		25	4	1.97		8	5	2.54		29	6	2.44		G14
6	4.24		23	10	1.87		24	10	2.47		27	2	2.34		G53
10	3.93		F	8	1.82		14	2	2.35		C	6	2.33		G10
1	3.21		29	1	1.80		28	1	2.30		26	8	2.30		G25
3	3.10		9	2	1.77		21	4	2.19		E	1	2.29		G27
12	2.87		E	10	1.77		19	1	1.92		20	2	2.17		G22
7	2.80		14	7	1.66		F	2	1.84		28	2	2.16		G29
10	2.72		24	1	1.54		29	9	1.74		2	10	2.10		G20
8	2.68		18	1	1.49		C	1	1.73		A	2	1.70		G47
4	2.02		27	2	1.47		B	7	1.62		B	2	1.69		G42
4	1.99		21	1	1.34		A	1	1.52		24	1	1.63		G24
2	1.75		20	3	1.34		33								
3	1.69		30	1	1.30		20								
3	1.50		28	2	1.28		9								
4	1.49		19	7	1.18		17								

TABLE A-7. MEAN VANADIUM CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP MUSCLE SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
5	1.74	--	19	10	ND	(2)	22	1	0.79	--	20	2	5.39	--	G24
1	1.28	--	29	3	ND	(1)	E	1	0.70	--	W14	2	1.95	--	G22
3	ND	(0)	28	3	ND	(1)	8	1	0.68	--	26	7	ND	(1)	G38
2	ND	(1)	20	10	ND	(1)	24	10	ND	(0)	2	8	ND	(0)	G20
4	ND	(0)	21	10	ND	(0)	25	7	ND	(1)	8	14	ND	(0)	G25
6	ND	(0)	23	7	ND	(0)	F	4	ND	(0)	E	22	ND	(0)	G54
4	ND	(3)	27	10	ND	(1)	27	1	ND	(0)	9	13	ND	(0)	G32
10	ND	(3)	24	3	ND	(0)	26	2	ND	(0)	D	10	ND	(0)	G34
2	ND	(0)	25	9	ND	(2)	17	10	ND	(3)	27	2	ND	(0)	G37
3	ND	(0)	30	2	ND	(1)	9	10	ND	(1)	22	2	ND	(0)	G42
10	ND	(2)	F	5	ND	(1)	33	2	ND	(1)	C	6	ND	(4)	G10
9	ND	(4)	14	2	ND	(0)	B	1	ND	(0)	A	7	ND	(3)	G14
5	ND	(0)	2	1	ND	(0)	20	2	ND	(0)	30	2	ND	(1)	G27
9	ND	(7)	8	3	ND	(0)	6	5	ND	(0)	29	2	ND	(1)	G47
1	ND	(0)	B	9	ND	(0)	21	3	ND	(0)	28	1	ND	(0)	G5
9	ND	(1)	17	9	ND	(0)	14	10	ND	(2)	F	2	ND	(0)	G19
5	ND	(4)	26	10	ND	(2)	19	9	ND	(3)	14	2	ND	(0)	G20
3	ND	(0)	9	3	ND	(0)	18	10	ND	(2)	23	2	ND	(0)	G53
12	ND	(0)	E	1	ND	(0)	A	10	ND	(1)	T14	2	ND	(0)	G29
10	ND	(0)	22	3	ND	(0)	28	10	ND	(0)	24	2	ND	(0)	D
8	ND	(1)	18	1	ND	(0)	29								

TABLE A-8. MEAN VANADIUM CONCENTRATIONS AND DUNCAN'S SUBSETS FOR SCALLOP VISCERA SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
1	74.2		B	2	35.06	—	E	9	21.26		14	6	13.16		G10
3	71.7		9	7	18.62		17	1	19.24		26	10	11.64		G20
6	67.3		26	2	17.66		9	10	16.91		27	7	11.39		G14
5	64.2		2	4	17.58		8	10	14.80		F	8	11.16		G25
10	62.8		8	2	17.37		B	2	14.78		30	2	11.06		G22
9	62.4		17	10	17.17		27	10	14.35		22	2	10.36		G53
12	56.7		E	9	16.78		22	10	13.49		23	2	9.97		G47
10	53.4		22	10	16.58		19	1	13.40		20	2	9.94		G29
10	50.2		24	10	15.88		14	9	12.97		2	2	9.15		G27
6	39.3		23	3	15.79		33	5	11.74		29	20	8.21		G54
8	37.1		18	4	13.47		21	8	10.86		T14	2	7.70		G42
7	36.1		14	10	13.31		24	4	10.09		E	2	7.28		G24
4	35.3		21	1	13.13		20	10	9.98		24	6	7.19		G38
10	32.0		F	6	12.54		F	1	9.74		W14	3	6.98		G32
2	31.7		20	1	11.33		18	1	9.11		D	2	6.86		G19
1	29.0		29	2	10.77		C	2	8.92		C	10	6.65		G34
3	28.3		30	3	10.30		28	7	8.44		8	1	5.15		G5
4	27.3		19	8	9.58		25	2	7.83		28	1	4.55		G37
2	26.8		25	1	8.81		29	1	7.76		A				
4	26.4		27	1	7.47		A								
3	21.0		28	3	6.88		26								

TABLE A-9. MEAN CADMIUM CONCENTRATIONS AND DUNCAN'S SUBSETS FOR OCEAN QUAHOG SAMPLES

March 1974				August 1974				February 1976				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
10	4.01	I	25	3	4.31	I	25	9	4.09	I	C12	1	3.60	I	G29
4	2.78	I	14	2	3.19	I	2	9	3.60	I	14	2	3.42	I	G34
10	2.62	I	27	10	2.39	I	8	10	3.60	I	27	2	3.40	I	G20
2	2.52	I	2	9	2.37	I	F	1	3.23	I	18	2	3.02	I	D
10	2.40	I	F	2	2.24	I	24	2	3.16	I	C	2	2.81	I	G25
3	2.36	I	24	3	2.19	I	9	9	3.05	I	25	10	2.43	I	G54
1	2.28	I	18	1	2.18	I	27	5	2.81	I	F	2	2.19	I	G19
6	2.08	I	28	7	2.16	I	17	8	2.70	I	24	2	2.13	I	G37
7	2.04	I	E	9	2.08	I	32	10	2.69	I	17	2	1.97	I	G38
1	1.98	I	D	8	1.95	I	18	6	2.65	I	23	2	1.86	I	G35
10	1.98	I	17	7	1.80	I	28	10	2.62	I	8	2	1.84	I	G42
5	1.90	I	29	10	1.79	I	E	9	2.53	I	2	2	1.80	I	G53
5	1.77	I	20	8	1.61	I	22	1	2.46	I	D	2	1.45	I	G14
4	1.76	I	.A	1	1.60	I	33	1	2.39	I	T14	2	1.45	I	G47
2	1.73	I	26					6	2.36	I	22	2	1.41	I	G32
10	1.73	I	9					5	2.27	I	H1				
2	1.68	I	B					8	2.26	I	9				
10	1.65	I	22					3	2.23	I	26				
6	1.48	I	C					1	1.06	I	20				

TABLE A-10. MEAN COPPER CONCENTRATIONS AND DUNCAN'S SUBSETS FOR OCEAN QUAHOG SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
6	11.30		28	2	13.23		24	8	7.51		9	2	9.25		G47
4	9.79		A	8	10.21		22	1	7.32		T14	2	9.07		G25
10	9.73		9	10	10.13		E	4	7.20		E	2	8.90		G32
5	9.67		20	9	10.00		32	3	7.07		M5	2	8.21		G34
2	9.55		2	10	9.82		8	5	6.96		H1	2	8.17		D
10	9.32		22	1	9.82		33	5	6.93		F	2	7.82		G53
6	8.86		C	7	9.41		17	6	6.45		22	12	7.58		G54
2	8.85		26	3	9.17		9	9	6.23		25	2	7.27		G19
7	8.60		E	8	8.39		18	1	6.19		18	2	6.32		G14
1	8.56		18	3	8.30		25	10	5.86		8	2	6.30		G20
1	8.40		D	7	7.96		28	1	5.82		20	2	6.28		G38
10	8.34		25	9	7.87		F	2	5.76		C	2	6.19		G5
2	8.22		B	2	6.13		2	6	5.67		23	2	5.33		G42
3	8.01		24	1	4.48		27	9	5.50		2	2	5.31		G37
10	7.88		17					8	5.42		24	1	4.52		G29
5	7.63		29					3	5.22		26				
10	7.13		27					1	4.80		D				
4	7.04		14					9	4.73		14				
10	6.64		F					10	4.73		27				
								10	4.50		17				
								9	4.44		C12				

TABLE A-11. MEAN NICKEL CONCENTRATIONS AND DUNCAN'S SUBSETS FOR OCEAN QUAHOG SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
4	13.36		14	3	18.36		25	3	29.29	—	MS	2	22.65		G20
6	11.73		28	2	16.29		24	10	14.45		27	2	13.51		G5
2	11.59		2	7	9.64		28	1	14.04		D	2	9.77		G25
10	11.22		27	10	8.97		E	5	13.31		F	2	9.23		G53
10	10.80		25	7	8.94		17	1	13.02		T14	2	9.16		G14
10	10.52		F	8	8.40		22	9	12.49		25	12	8.30		G54
5	9.56		20	8	7.59		18	9	11.38		C12	2	8.19		G34
1	9.55		18	9	7.32		F	6	11.05		23	2	7.70		G19
3	9.11		24	10	7.19		8	9	10.95		14	2	7.40		G32
5	8.85		29	9	6.79		32	1	10.24		18	1	6.92		G29
4	8.34		A	2	6.69		2	1	10.03		20	2	6.43		D
6	7.35		C	1	5.84		27	8	9.99		24	2	4.75		G42
1	6.89		D	3	5.41		9	3	9.87		26	2	4.32		G38
10	6.77		17	1	4.04		33	9	9.75		2	2	4.00		G47
10	6.63		9					6	9.30		22	2	3.05		G37
2	6.61		B					4	9.03		E				
10	6.56		22					10	8.77		17				
7	5.22		E					2	7.74		C				
2	4.21		26					10	7.45		8				
								8	7.41		9				
								5	5.42		H1				

TABLE A-12. MEAN VANADIUM CONCENTRATIONS AND DUNCAN'S SUBSETS FOR OCEAN QUAHOG SAMPLES

March 1974				August 1974				February 1975				June 1975			
n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta	n	$\bar{x}$	D	Sta
10	20.63	–	9	3	4.30		9	5	3.11		H1	2	2.88		G34
10	19.97		22	7	3.71		17	1	3.03		T14	2	2.73		G5
2	16.72		26	2	3.48		24	9	2.92		C12	2	2.39		G47
7	15.42		E	1	3.39		27	3	2.89		M5	2	2.39		G19
10	15.20		17	1	3.32		33	9	2.83		14	12	2.22		G54
1	13.20		D	2	3.06		2	8	2.77		24	2	2.14		G20
3	12.63		24	8	3.02		22	5	2.75		F	2	2.12		G38
2	11.44		2	9	2.77		32	6	2.61		22	2	1.96		G32
6	8.76		C	10	2.48		8	2	2.54		C	2	1.95		G25
2	8.69		B	10	2.38		E	10	2.53		17	2	1.90		G37
5	8.54		20	7	2.10		28	6	2.35		23	2	1.83		D
10	7.83		27	9	1.70		F	10	2.32		8	2	1.56		G14
1	7.14		18	2	1.59		25	9	2.31		27	1	1.52		G29
5	6.53		29	8	1.57		18	8	2.30		9	2	1.51		G53
4	6.38		14					9	2.15		2	2	1.26		G42
4	6.18		A					9	2.07		25				
6	5.82		28					3	1.95		26				
10	4.57		F					1	1.88		18				
10	4.25		25					1	1.84		D				
								4	1.76		E				
								1	1.64		20				

APPENDIX B

BIOASSAY RESULTS

The following bioassay results have been supplied to the U.S. Environmental Protection Agency, Environmental Impacts Branch, Region III, Philadelphia, PA by E.I. DuPont de Nemours and the City of Philadelphia as a condition of their EPA ocean disposal permits, DE 011 and PA 012, respectively. These are a summary of a year's worth of analyses and may be considered as indicative of the general level of toxicity of the respective wastes.

TABLE B-1. TOXICITY OF DUPONT IRON ACID WASTE, 96 HOUR TL50

Species	Concentration of Waste
Pseudopleuronectes americanus (fish)	200-400 PPM
Crangon septemspinosa (shrimp)	203-625 PPM
Acartia tonsa (copepod)	35-72 PPM

TABLE B-2. TOXICITY OF PHILADELPHIA SEWAGE SLUDGE, 96 HOUR TL50

Species	Concentration of Waste
Menidia menidia (fish)	1350-1700 PPM
Acartia tonsa (copepod)	9-33 PPM
Skeletonema costatum (diatom)	26-29 PPM

Thus, the two species of fish demonstrate the greatest resistance to the toxic properties of the two wastes. These animals also possess the greatest potential for avoidance of waste laden water by mean of locomotion. The two planktonic species, on the other hand, exhibit the greatest sensitivity to the wastes. This is particularly significant since Acartia is a recognized standard organism for such bioassay determinations. Moreover, it feeds on the same size range of food particles as do the shellfish in this study. It particularly thrives on Skeletonema. In any case, this means that at a given site, the menu of Acartia and the filter feeding mollusc, Placopecten, would be expected to be similar, if not identical. Thus the incorporation of the waste materials, along with their thus demonstrated toxic properties, into the shellfish food chain in the vicinity of these ocean disposal sites is an obvious potential problem.